Primary Production and Related Limnological Data for Some Lakes of the Yellowknife, NWT Area

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by

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ABSTRACT

Fee, E.J., M.P. Stainton, and H.J. Kling. 1985. Primary production and related limnological data for some lakes of the Yellowknife, NWT area. Can. Tech. Rep. Fish. Aquat. Sci. 1409: v + 55 p.

Physical, chemical, and biological data collected from Great Slave Lake and a series of smaller lakes in the Yellowknife area during the months of June, July and August of 1983 are described.

Detailed descriptions of sampling procedures and sample preparation methods are given. Internal consistency checks on the chemistry data showed that our methods of preserving samples for later analysis were reliable. Dissolved inorganic carbon (DIC) values calculated from pH, temperature, and alkalinity averaged 24% higher than directly measured DIC values, indicating that the common use of the former procedure to obtain DIC values required for primary production calculations is a potential source of important errors. Three methods of measuring chlorophyll were compared. The standard method (gross fluorescence of a methanol extract) gave higher values than methods designed to measure chlorophyll *a* more specifically. However, the ratios of the results given by the different chlorophyll methods were the same in lakes having different dominant phytoplankton species and productivities. In light of this, and in order to maintain comparability with results from other studies, we used results from the standard method throughout the rest of the report.

The lakes of this region are chemically diverse, with conductivities ranging from 30-285 $\mu S \cdot cm^{-1}$. The chemistry of Yellowknife Bay changed seasonally due to seasonally varying inputs of water from terrestrial watersheds and from Great Slave Lake. One lake (Madeline) had a very peculiar chemical composition.

Phytoplankton biomasses ranged from 105-2600 $\mu gC \cdot L^{-1}$ and chlorophyll concentrations from 0.8-7.8 $\mu g \cdot L^{-1}$. Chrysophytes, cryptophytes and diatoms were the dominant phytoplankton groups. The phytoplankton species composition in Great Slave Lake was essentially unchanged from the 1950's. There were, however, some changes of dominant phytoplankton species in Yellowknife Bay from the 1970's.

Phytoplankton primary production was related to concentrations of suspended phosphorus and nitrogen but was not related to total ionic strength (conductivity) or to the concentrations of dissolved forms of these nutrients. The rate of photosynthesis per unit of chlorophyll was higher in waters influenced by the Slave River than in waters that received runoff only from the Canadian Shield. Algal nutrient deficiency indicators showed the same separation between these two water types; samples from Shield waters were more consistently and severely deficient than those from locations influenced by Slave River waters.

The use of phytoplankton primary production data for the management of fish populations in the NWT is discussed. Since 1970, commercial fish harvests from the western basin of Great Slave Lake have been five to 10 times greater than have been observed in other lakes with its level of primary production. If this result is correct, this lake is either unusually efficient at producing fish from primary production or it is being overfished. However, we gathered data from only one part of the lake and for only a portion of the growing season. Our primary production estimates for this lake therefore require verification. This could be done by making ship-borne primary productivity measurements during an entire ice-free season and from all regions of the lake.

Key words: limnology; Great Slave Lake; phytoplankton; nutrients; major ion chemistry; temperature; transparency; primary production; chlorophylls; fisheries management.

RESUME

Fee, E.J., M.P. Stainton, and H.J. Kling. 1985. Primary production and related limnological data for some lakes of the Yellowknife, NWT area. Can. Tech. Rep. Fish. Aquat. Sci. 1409: v + 55 p.

On décrit dans ce rapport des données physiques, chimiques et biologiques recueillies dans le Grand lac des Esclaves et plusieurs autres plus petits lacs de la région de Yellowknife pendant les mois de juin, juillet et août 1983.

On décrit avec précision les méthodes d'échantillonnage et de préparation des échantillons. Les vérifications internes pratiquées pour s'assurer de la cohérence des données chimiques ont indiqué que nos méthodes de préservation des échantillons à des fins d'analyse ultérieure étaient fiables. Les valeurs de carbone inorganique dissous (CID) calculées à partir des taux de pH, de la température et de l'alcalinité se sont élevées en moyenne à 24 % de plus que les valeurs de carbone inorganique dissous mesurées directement, ce qui indiquait que l'utilisation commune de la première méthode de calcul des valeurs de CID requises pour établir les données de production d'organismes primaires peut causer des erreurs importantes. On a comparé trois méthodes de mesure de la chlorophylle. La méthode standard (fluorescence élémentaire d'un extrait de méthanol) a produit de plus grandes valeurs que les méthodes destinées plus précisément à mesurer la chlorophylle *a*. Les ratios des résultats obtenus par les différentes méthodes de mesure de chlorophylle étaient toutefois les mêmes dans des lacs qui recelaient des espèces et des taux de productivité de phytoplanctons différents et dominants. À la lumière de ces indications, nous avons eu recours aux résultats issus de la méthode standard pendant tout le reste de la recherche.

La composition chimique des lacs de cette région varie, les taux de conductibilité pouvant s'échelonner de 30 à 285 $\mu S.cm^{-1}$. La composition chimique de la baie de Yellowknife a subi des variations saisonnières, en raison des changements de l'apport en eau des bassins hydrographiques terrestres et du Grand lac des Esclaves. Un lac (le lac Madeline) avait une composition chimique très particulière.

Les biomasses de phytoplancton variaient de 105 à 350 $\mu gC.L^{-1}$, tandis que les taux de concentration de chlorophylle pouvaient s'échelonner entre 0,8 et 7,8 $\mu g.L^{-1}$. Les groupes phytoplanctoniques dominants étaient les chrysophytes, les cryptyophytes et les diatomées. La composition des espèces de phytoplanctons du Grand lac des Esclaves est demeurée pratiquement inchangée depuis les années cinquante. On a toutefois remarqué certains changements pour ce qui est des espèces dominantes de phytoplancton dans la baie de Yellowknife, par rapport aux années soixante-dix.

La production primaire de phytoplanctons était en partie fonction des concentrations de phosphore et de nitrogène en suspension; la résistance ionique globale (conductibilité) ou les concentrations de composés dissous de ces éléments nutritifs n'avaient cependant aucune incidence sur la production primaire. Le taux de photosynthèse par unité de chlorophylle était plus élevé dans les eaux sous l'influence de la rivière des Esclaves que dans les eaux qui recevaient uniquement l'écoulement du Bouclier canadien. Les indices de déficience en apport nutritif algacé ont reflété la même dichotomie entre ces deux eaux. Les échantillons obtenus des eaux du Bouclier indiquaient une déficience plus persistante et grave que celle observée dans les échantillons recueillis à des endroits sous l'influence des eaux de la rivière des Esclaves.

On aborde dans ce rapport l'utilisation des données sur la production primaire des phytoplanctons aux fins de la gestion des populations de poisson dans les T.N.-O. Depuis 1970, la pêche commerciale dans le bassin occidental du Grand lac des Esclaves a été de cinq à dix fois plus importante que celle observée dans d'autres lacs affichant le même taux de production primaire. Si ces données s'avèrent exactes, cela signifie que ce lac est anormalement efficace, pour ce qui est de l'entretien des populations de poisson à partir de la production d'organismes primaires, ou qu'on y pratique une pêche excessive. Nous n'avons toutefois obtenu des données que d'une partie du lac et pendant une seule tranche de la saison de croissance. Notre évaluation de la production primaire de ce lac doit donc être vérifée. Cela pourrait s'effectuer en mesurant les taux de productivité primaire à partir d'embarcations, pendant toute une saison sans glace et dans toutes les parties du lac.

Mots-clés: limnologie; Grand lac des Esclaves; phytoplancton; élément nutritif (minéral); composition chimique ionique dominante; température; transparence; production primaire; chlorophylle; gestion de la pêche.

INTRODUCTION

The mineral and hydroelectric resources of the Northwest Territories (NWT) are currently being developed at an accelerating rate. Recognizing that such developments can affect the natural environment, the Science Advisory Board of the Government of the Northwest Territories sponsored a review of the state of knowledge of the aquatic resources of the Northwest Territories. One of the goals of this study was to identify areas that needed further research. The report produced by this Board (McCart and Den Beste 1979) gave highest priority to this recommendation: "There should be further study of the productivity of freshwater ecosystems and development of indices to fish productivity".

Several recent papers have demonstrated that phytoplankton primary productivity data can be used to estimate fish productivity (Oglesby 1977; Hecky et al. 1981; Liang et al. 1981; McConnel et al. 1977; Melack 1976; Mills and Schiavone 1982). During the past 12 years the Freshwater Institute (FWI) has developed sophisticated methods to measure phytoplankton primary productivity. As this Institute has the responsibility to manage fisheries in the NWT, a study of the feasibility and potential utility of applying these methods to large and/or remote lakes in the NWT was undertaken in the summer of 1983.

An important goal of our work was thus to examine the usefulness of phytoplankton primary production data in predicting potential fish yields from NWT lakes. We further wanted to determine whether the sampling and experimental procedures that are used to measure productivity in other FWI programs could be easily adapted to studying a diverse group of remote and/or large lakes of the NWT. This report gives detailed descriptions of these methods and summarizes the data that were obtained.

STUDY AREA

Yellowknife (62°27'N, 114°21'W), the capital of the NWT, was the centre of our field operations. The city is located on the edge of the Canadian Shield (see Brunskill 1985, and Healey and Woodall 1973 for summaries of climatic, geological, and limnological information for the Yellowknife region), and a great diversity of lakes are located nearby. Yellowknife also offered the logistic advantages of having modern laboratory facilities, excellent charter aircraft service, and daily scheduled flights to Winnipeg, where many of the analyses were to be performed.

Except for Great Slave Lake (GSL), the drainage basins of all of the lakes chosen for study are located entirely on the Canadian Shield. The locations of the lakes that were included in our sampling program are shown in Fig. 1 and their physical features are summarized in Table 1.

Madeline Lake is a small lake accessible by road or a 10 minute flight from Yellowknife (see Falk (1979) for background data). The Chitty lakes (Chitty, Drygeese, Alexie, and Baptiste) are medium sized lakes which can be reached by a 15 minute flight from Yellowknife. The fish populations of these lakes have been studied for more than 10 years (Healey 1975, 1978a, b, 1980; Healey and Woodall 1973). Prosperous Lake is a large lake accessible by road or by a 5 minute flight from Yellowknife (see Falk 1979 for background data). Gordon Lake is a very large lake about 1 hour by air to the northeast of Yellowknife.

Several part of Great Slave Lake were studied: Yellowknife Bay is immediately adjacent to Yellowknife. This bay receives sewage and mine wastes from the city of Yellowknife and its water quality has been the subject of several investigations (Bell et al. 1975; Moore 1980a; Moore et al. 1978). Figure 2 shows the locations of our sampling stations in the Bay. The West Basin of GSL is a huge and sometimes turbid waterbody that has supported commercial fisheries since 1945. McLeod and Christie Bays are deep and clear. These bays were commercially fished in the past but they are now closed to commercial fishing to protect sport fisheries. Hearne Channel is a region of transition, connecting the West Basin with Christie Bay.

METHODS

The following measurements were made at 79 stations between 19 June and 17 August 1983:

- Vertical profiles of temperature and light.
- Water chemistry, including concentrations of nutrients and chlorophyll.
- Phytoplankton primary production in a controlled light incubator.
- Phytoplankton species and phytoplankton and protozoan biomasses.

SAMPLING STRATEGY

The stations in Yellowknife Bay were sampled from a boat powered by a small outboard motor. All other lakes were sampled from the pontoon of a Turbo Beaver floatplane. The Environmental Protection Service Water Laboratory in Yellowknife was used for initial sample processing.

Preserved chemical samples and scintillation vials containing ^{14}C productivity samples were shipped by air to the Freshwater Institute in Winnipeg the day after sampling. Prior to shipment, all samples were kept in the dark and refrigerated. Filtered samples were also dried in an evacuated desiccator. Samples were received in the Winnipeg laboratory within three days from the day of shipment.

TEMPERATURE AND LIGHT

Temperature vs depth profiles were measured with a Whitney CTU-3B resistance thermometer

that was calibrated in the laboratory with a mercury thermometer. Light vs depth profiles were measured with a Licor LI-192S cosine response underwater quantum sensor used in conjunction with an LI-185 meter. A 0.25 m diameter Secchi disk was used as an auxiliary measure of transparency. The absorbance of an unfiltered fresh water sample was measured in the Yellowknife laboratory with a Bausch and Lomb Spectronic 100 spectrophotometer at a wavelength of 543 nm using a 10 cm cuvette. This measurement was taken to determine whether absorbance measured in the laboratory would be correlated with *in situ* extinction of light.

WATER SAMPLING

Water samples were taken from the surface to the bottom of the mixed layer with the integrating sampler described by Shearer (1978). This sampler is a harness that accepts a 4 L glass bottle. Attached to the bottom of the harness is an epoxy coated lead weight of sufficient mass to submerge the empty bottle. Hydrostatic pressure forces water into the sampler. To protect phytoplankton from exposure to high surface irradiances, sample bottles were of amber glass wrapped in black electrical tape. Samples were transported to the laboratory in individual insulated boxes. The period from the time of sampling until the time the samples arrived at the laboratory was 0.5-2 h for the Yellowknife Bay stations and from 1-6 h for the stations sampled by aircraft. Sample bottles were cleaned with concentrated HCl followed by five rinses of tap water and three rinses of distilled water.

CHEMICAL DETERMINATIONS

Unless otherwise specified, chemical concentrations were measured in Winnipeg at the Freshwater Institute chemistry laboratory using methods given in Stainton et al. (1977).

Sample preparation and analytical methods

Chlorophyll: In the Yellowknife laboratory, an aliquot of 150-750 mL of whole lake water was filtered through a Whatman GF/C filter. In Winnipeg, the pigments on these filters were extracted with 95% methanol for 16 h at -10°C. The extract was analysed by three different methods: spectrophotometric, gross fluorescence, and high performance liquid chromatographic (HPLC) separation of constituent pigments followed by fluorescence detection. The spectrophotometric method measured absorbance in a 1 cm path at 650 and 665 nm corrected for absorbance at 700 nm. The gross fluorescence method was that described in Stainton et al. (1977). The HPLC method used a C18 reverse phase column (Waters "Resolve"®) to separate pigments in a 100 µL sample of extract. The eluent consisted of methanol (68%), acetone (27%), and water (5%) and was pumped at 2 $mL \cdot min^{-1}$. The separated pigments were detected with a Turner III fluorometer equipped with a flow-through cell. All three determinations were performed within 15 minutes of each other. The three methods were all calibrated using pure chlorophylls *a* and *b* (Sigma Chemicals), whose concentrations were determined using the extinction coefficients from Mackinney (1941). Although these extinction coefficients are for chlorophylls *a* and *b* in 100% methanol, previous work in the Winnipeg laboratory has confirmed their values in 95% methanol.

DOC, TDN, TDP: Water for analyses of dissolved organic carbon (DOC), total dissolved nitrogen (TDN), and total dissolved phosphorus (TDP) was filtered through a GF/C filter and shipped in 25 mL glass scintillation vials. The DOC samples were preserved with mercuric chloride. The TDN and TDP samples were preserved with 4N sulphuric acid.

Conductivity, pH, silica, and major ions: Water for these analyses was shipped in 25 mL plastic scintillation vials. The water for pH, conductivity, and silica was unfiltered and unpreserved. The water for chloride and sulphate was filtered and unpreserved. The water for sodium, potassium, calcium, and magnesium was filtered and preserved with 3N NCl.

DIC: a 125 mL sample was siphoned into a ground-glass stoppered bottle for dissolved inorganic carbon (DIC) analysis.

Alkalinity: A 125 mL sample was siphoned into a plastic bottle for alkalinity analysis. Alkalinity was determined in Winnipeg by titrating 100 mL of sample with 0.01 N HCl using a Metrohm model 636 Titroprocessor. End points were determined by Gran plot calculation.

Particulate C and N: 100 mL of water was filtered onto a GF/C filter for particulate carbon and nitrogen analyses.

Suspended P: 100 mL of water was filtered onto a GF/C filter for suspended phosphorus analyses.

TSS: The remainder of the sample (at least 100 mL and usually more than 500 mL) was filtered through a preweighed GF/C filter for analysis of total suspended solids.

PHYTOPLANKTON AND PROTOZOAN BIOMASSES AND DOMINANT PHYTOPLANKTON SPECIES

A 125 mL sample of whole water was preserved with acid Lugols solution. Aliquots of 10 mL were analyzed in Winnipeg with a Wild M40 microscope following the Utermohl inverted microscope method modified by Nauwerck (1963). Taxonomy follows that given in Findlay and Kling (1979). Cell volumes were calculated from the cell dimensions and geometric shapes and biomasses were calculated assuming a specific gravity of 1.0 for phytoplankton.

PHYTOPLANKTON PRIMARY PRODUCTION

Samples for determination of phytoplankton primary production were processed in the Yellowknife laboratory. A silicone rubber tube was used to siphon water from the 4 L field sample

bottle into an acid-washed 1 L Pyrex® glass bottle. A disposable plastic syringe fitted with a short length of Tygon® tubing was used to add 3 mL of ^{14}C stock solution (5.55×10^5 Bq·mL^{-1} = 15 μCu·mL^{-1}) to the 1 L bottle. After gentle agitation, 10 or 12 Pyrex® bottles of 64 mL capacity were filled by siphoning (silicone rubber tube) from the 1 L bottle. Replicate 64 mL bottles were placed in an artificial light incubator (Shearer et al. 1985) at four or five light levels. Another set of replicates was placed in the dark to measure background ^{14}C uptake. Temperatures in the incubator were maintained within 2°C of in situ temperatures during incubation. After incubating for 3-4 h the bottles were removed from the incubator and 2.5 mL aliquots were put in scintillation vials. To remove unfixed inorganic ^{14}C, 0.5 mL of 0.1 N HCl was added to each vial and the resulting solution (pH = 2-3) was bubbled with air for 20 min using the apparatus described by Shearer et al. (1985). The amount of ^{14}C available for uptake was measured for each sample by pipetting 5 replicates of 1.5 mL of water from one of the incubated bottles with an Oxford Macro pipettor into scintillation vials that contained one mL of pH 10 buffer. Light levels in the incubator were measured at least twice and usually 4 or 5 times during the incubation period with a Biospherical QSL-100 spherical quantum sensor.

In Winnipeg the radioactivity in the scintillation vials was assayed on a Beckman LS2800 liquid scintillation counter using PCS fluor (Amersham). Raw counts were converted into absolute disintegrations using the "H-number" method which is built into the counter. The equations given in Shearer et al. (1985) were used to compute volumetric carbon uptake rates from the ^{14}C disintegrations, dissolved inorganic carbon concentrations, and ^{14}C standards. The programs described in Fee (1984) were used to calculate the photosynthetic parameters P^B_m (the rate of carbon uptake at saturating irradiances per unit of chlorophyll) and α (the slope of the light limited part of the curve relating carbon uptake per unit of chlorophyll to light) from the carbon uptake rates, chlorophyll concentrations (standard fluorometric method), and incubator irradiances. These programs were also used to simulate in situ production from the photosynthetic parameters, water transparency data, and simulated cloudless irradiances (built into the program). They were also used to compute the daily mean irradiances in the mixed layer.

RESULTS

The data are summarized in Appendices 1-8. In all of these appendices "NA" stands for "data not available".

STATION LIST

Appendix 1 lists the stations sampled, the date and time of sampling, the depths sampled, and field and incubator temperatures.

PHYSICAL DATA

Appendix 2 contains the temperature profile data. Appendix 3 contains the transparency profile data. Appendix 4 contains transparency related data: Secchi depths and colors, absorbances of whole water samples at 543 m, in situ extinction coefficients, and mean water column irradiances.

CHEMICAL DATA

Appendix 5 contains all of the chemical data except for chlorophyll.

BIOLOGICAL DATA

Appendix 6 contains the phytoplankton and protozoan biomass and phytoplankton species composition data. Appendix 7 contains the incubator primary production data. Appendix 8 contains the photosynthetic parameters, chlorophyll concentrations, and daily integral primary productions.

DISCUSSION

LOGISTICS

With one exception, all water bodies could be sampled regularly by fixed wing aircraft which allowed quick access to very remote lakes. Two problems were encountered when sampling by airplane. 1) The open waters of the West Basin of Great Slave Lake could be sampled in this way only during the period immediately after ice-out. During midsummer, long surface waves ("rollers") persisted even after three days of calm weather and made landing on this waterbody dangerous. A ship is needed to sample lakes of this size. 2) In order to measure in situ transparency - which must be known or estimated in order to simulate in situ production with primary production models - it is necessary to sample when there is little wind or to anchor the plane. The latter is feasible only on the smaller lakes. However, there was a high correlation ($r = 0.91$) between the absorbance of a whole water sample measured in the laboratory and in situ transparency (Fig. 3), and this relationship may be used if it proves to be impossible to measure transparency in the field.

Shipping samples to Winnipeg for analysis not only reduced costs but also ensured that the results are comparable to those of other research programs at the FWI.

PHYSICAL AND CHEMICAL PROPERTIES

Chemical consistency checks

Because chemical samples were partitioned and preserved in Yellowknife and then shipped to Winnipeg for analysis, it was important to establish that the additional manipulations and analysis of subsamples provided a cohesive chem-

ical characterization of the samples. As is often the case in surveys of this type, sampling sites were chemically and physically characterized in enough detail to permit several consistency checks to be made.

Measured vs calculated conductivity: The first check is the comparison between measured and calculated conductivity, where calculated conductivity is the sum of the molar concentrations of the individual anions and cations multiplied by their respective specific ionic conductances. The assumptions inherent in this calculation - that all ions act independently and are fully dissociated - are most valid in dilute samples.

In our data, measured and calculated conductivities showed excellent agreement in Shield waters, where conductivities were below 140 $\mu S \cdot cm^{-1}$ (Table 2 and Fig. 4). Samples from waters influenced by the Slave River had conductivities above 140 $\mu S \cdot cm^{-1}$. In these waters calculated values were on average 11% higher than measured. This discrepancy is probably due to interionic effects and lack of complete dissociation.

Cation/anion balance: Another simple and useful consistency check is the balance between cations and anions (Fig. 5). On average, there was a 6% excess of anions over cations.

Calculated vs measured DIC: The final consistency check was obtained by comparing calculated with measured dissolved inorganic carbon (DIC) concentrations. This is the most interesting of the three consistency checks, since many studies that need DIC values for calculating primary production with the ^{14}C method do not measure it directly (as was done here) but calculate it from temperature, total alkalinity, and pH data.

When we calculated DIC in this manner, we obtained values that averaged 24% higher than the DIC values that we measured (Fig. 6). This means that either our measured DIC values are low, or the assumption that measured alkalinity is due entirely to inorganic carbon is false. The previously observed good agreement between measured and calculated conductance, which was obtained using bicarbonate calculated from measured DIC and pH, suggests that our measured DIC data are accurate. We conclude, therefore, that some of the alkalinity was not supported by the inorganic carbon system.

The titration curves produced by the instrument used to measure alkalinity were reanalyzed from this point of view. Almost all curves had two inflections (end points); one at pH 5.3-5.4 due to bicarbonate, and one at pH 7.2-7.4 due to unknown species. Since at the pH of these samples there is essentially no carbonate or silica-based alkalinity, corrected estimates of "bicarbonate only" alkalinity were obtained by subtracting the amount of acid required to reach the first end point (pH 7.3) from the total required to reach the final end point (pH 5.3), thus removing the contribution of unknown species. When this "corrected" alkalinity was used to calculate DIC, the results were within 4% of our measured DIC values (Fig. 6). Based on studies that one of us (MPS) has made on lakes located in the Experimental Lakes Area (ELA) in northwestern Ontario, we believe that the non-DIC based alkalinity present in these samples is due to organic chemical species.

The observed presence of non-DIC (probably organic) alkalinity is certainly not unique to Yellowknife and ELA. This means that the indiscriminate use of total alkalinity and pH measurements to estimate the DIC available for primary productivity can produce large errors in ^{14}C uptake measurements.

We conclude that the three consistency checks showed good agreement within our dataset. Subsamples for DIC, pH, conductivity, anions, and cations appear to have been prepared, preserved, and transported in a usable manner.

Chemical composition of individual lakes

Excepting Madeline Lake, which is a special case, Table 3 shows that there are two major water types in the Yellowknife area which can be readily distinguished by their conductivities; Canadian Shield waters, with conductivities less than 140 $\mu S \cdot cm^{-1}$, and Slave River waters, with conductivities greater than 140. Among the lakes whose drainage basins are located entirely on the Canadian Shield (again, excluding Madeline Lake), conductivity varied by a factor of four. The lowest values (30 $\mu S \cdot cm^{-1}$ in McLeod Bay) correspond to the highest values reported for ELA lakes, an intensively studied group of Canadian Shield lakes in northwestern Ontario (Armstrong and Schindler 1971). The Chitty Lakes values are about four times greater than the highest ELA values.

Madeline Lake: This lake is chemically anomalous. All measured chemical constituents were higher than at other sites in spite of the fact that the lake drains into and is bounded by the same geological formations as Prosperous Lake, which has conductivities only one-sixth that of Madeline. A heavily used gravel road (the Ingraham Trail) that runs close to the south shore of this lake is the probable source of these elevated chemical concentrations.

Yellowknife Bay: Conductivities in this bay were much more variable than in any of the other sampled waterbodies. This variability is caused by the mixing in the bay of Shield waters from Yellowknife River (the source of which is Prosperous Lake) and Slave River waters, which predominate in the West Basin of Great Slave Lake. Early in the season, ion concentrations at the innermost stations (1, 2, 3, and 4; see Fig. 2 for station locations) are low because spring runoff from the land adds large quantities of dilute Shield waters to the Bay (Moore et al. (1978) give data on the timing of runoff into the bay). As the season progresses, runoff from the land declines and the proportion of Great Slave waters at these stations increases. Figure 7 shows the effect of these processes on

the seasonal patterns of silica in the bay. All other major ions showed the same temporal and spatial trends as silica, which was chosen for illustration because it had the largest difference between the two source waters (Prosperous Lake and the West Basin of GSL). Note that the low early season silica values at the innermost stations in Yellowknife Bay are actually double the nighest value measured in Prosperous Lake, and are not due to silica utilization by diatoms because diatoms were not abundant in the bay at that time (Kling, unpublished data).

Water temperature (through its effect on density) controls the rate of mixing of Shield and Slave River waters in Yellowknife Bay. This conclusion follows from these facts (see Fig. 7):

- Before 28 July locations 1-4 were warmer (less dense) than at location 6 and mixing was slow.
- On 2 August when temperatures were the same at all locations, mixing was apparently complete as there were no chemical differences in the Bay.
- After 3 August locations 1-3 again became warmer than location 6 and the previous chemical differences reappeared.

On 28 July temperatures and chemical concentration data indicate the existence of coherent plumes in the Bay. The water at locations 2 and 3 near the head of the Bay was like that at location 6 at the mouth, while location 5 near the mouth of the By had characteristics similar to location 1.

Because the bay is shallower than the West Basin, it heats faster in the spring. If it also cools faster in the autumn, then it can be expected that waters from the West Basin will mix into the bay more quickly at that time. However, temperature differences between inshore and offshore waters in large lakes are greater in the spring than in the autumn (Hecky 1984) so observations are needed to confirm this expectation.

The water chemistry at location 6 did not vary greatly with time (Fig. 7). There were, however, extreme variations of temperature and transparency during a short time period at this location (Fig. 8). This rapid change of temperature and transparency did not occur at any of the other Yellowknife Bay stations and can only be due to large scale water motions in the main mass of water in the West Basin. Although this location is clearly nearshore, the stability of its chemical composition coupled with the variability of its physical environment are clear indications of a strong West Basin influence.

Christie Bay: This bay had transparencies and temperatures that were similar to those observed in McLeod Bay, but concentrations of major ions that were much more similar to the West Basin than to McLeod Bay (Table 4). This may be due partially to the presence of Precambrian carbonate rocks in the Christie basin; however, satellite images demonstrate that when the wind blows from the southwest, West Basin waters move through Hearne Channel toward Christie Bay. These incursions of West Basin waters are probably the main reason for the chemical similarity of Christie Bay and the West Basin.

McLeod Bay: This bay had the most dilute waters in the region. This is due to the fact that its basin contains only very shallow soils on top of insoluble granites and gneisses. The tree line touches the north edge of this bay and much of the basin is exposed bedrock. McLeod Bay is connected to the rest of the lake by only a narrow and shallow channel which limits exchange and prevents the higher salt concentrations in the other parts of Great Slave Lake from influencing its chemical composition.

Although McLeod Bay is extremely dilute, it along with Christie Bay, has the highest nitrate levels found in GSL, being 10 to 20% of total dissolved nitrogen.

Comparison with results from other studies

Table 5 compares the mean concentrations of chemical constitutents in each of the lakes that we studied with values reported for these same lakes in 1971 and 1972 (Brunskill 1985; Healey and Woodall 1973). Values for pH, total dissolved nitrogen, calcium, sodium, and potassium agree well in all three datasets. Discrepancies between these three datasets are: 1) the 1971 conductivity values are erratic (both high and low) compared to the other two; 2) the 1983 HCO_3 values are 11-24% lower than the other two; 3) the 1971 and 1973 silica values are 15-50% higher than the 1983 values; 4) the 1983 TDP values are only one-third to one-half of the earlier values; and 5) the 1971 and 1973 magnesium values are 10-78% higher than the 1983 values. Explanations for the conductivity and HCO_3 discrepancies are: the 1971 conductivity measurements were made with an instrument that had poor sensitivity (Brunskill, personal communication). The 1971 and 1972 HCO_3 values probably resulted from the fact that they were calculated from alkalinity, pH, and temperature instead of being measured directly (see the section Calculated vs measured DIC above). We have no explanation for the consistently lower silica, TDP, and magnesium values obtained in 1983.

Chlorophyll measurements

Chlorophyll is usually estimated with solvent extraction followed by measurement of gross fluorescence (Stainton et al. 1977). This method measures to varying degrees all fluorescing pigments, including phaeopigments which do not participate in photosynthesis. In this study we attempted to measure chlorophyll *a* with more specific techniques in the hope that *a* better correlation would be observed between the concentration of photosynthetic pigments and properties of the photosynthesis vs light curves.

The more specific methods appear to have isolated chlorophyll *a*: the spectrophotometric method averaged 83% of gross fluorescence and the HPLC method averaged 66% of gross fluores-

cence. However, the estimates given by these more specific techniques gave no better correlation with primary productivity than the standard gross fluorescence method. Further, the ratios of the results given by the different methods were similar in all lakes, regardless of their species composition or productivity. Therefore, we refer hereafter to results given by the standard gross fluorescence method when chlorophyll values are cited.

PHYTOPLANKTON BIOMASS AND SPECIES COMPOSITION

Table 6 summarizes the mean phytoplankton biomasses and percent compositions for the studied lakes. Chrysophytes were dominant in all lakes except the offshore region of the West Basin of Great Slave Lake (diatoms) and Madeline Lake (blue-greens).

Great Slave Lake

Three grups (chrysophytes, cryptophytes, and diatoms) formed the bulk of the phytoplankton community in Great Slave; cyanophytes and euglenoids were rarely present in any part of the lake. The greatest biomasses occurred on 27 June at Station 13 in the Western Basin (893 $\mu g \cdot L^{-1}$) and on 30 June at the Kam Point station (location 6) in Yellowknife Bay (1346 $\mu g \cdot L^{-1}$). The two samples from McLeod Bay had the lowest biomasses (164 $\mu g \cdot L^{-1}$ on 5 July and 105 g L^{-1} on 8 August).

Western Basin of Great Slave Lake: Certain taxa were always present in low numbers in Western Basin samples and serve to characterize this phytoplankton community since they wre rare or absent in the other parts of the lake. These taxa are large centric diatoms (Stephanodiscus rotula Kutz., S. niagarae Ehrenb., and Cyclotella comta (Ehren.) Kutz.), Nitzschia spp., Rhizosolenia eriense var. morsa W. et G.S. West Bicosoeca accreta Hibbard (lorica containing numerous particles of detritus), and the diatom Diatoma elongatum (Lyngb.) Ag.

Our samples from the Western Basin proper were taken in June immediately after ice-out. At this time the diatom Melosira islandica O. Muller was dominant at stations 9, 10, 11, and 13. Two stations (12 and 14) had high detritus loads and at these stations M. islandica was of secondary importance. Station 12 was directly in the turbid plume of the Slave River and the cryptomonad Rhodomonas lacustris Pasch. et Ruttn. was dominant. Station 14 was at the edge of the rapidly retreating ice pack and the dinoflagellate Peridinium inconspicuum Lemm. was dominant.

We have no samples from the offshore waters of the Western Basin after June. We do, however, have detailed data for the period from ice-out to mid-August at the Kam Point station in Yellowknife Bay. As mentioned previously (see Yellowknife Bay section), data from this station are strongly influenced by and probably are representative of the inshore West Basin waters. Except on 22 July and 17 August, when cryptophytes were more abundant, chrysophytes dominated at this station. Diatoms were always of second or third importance. Major chrysophyte species at this location were Uroglena americana Calkins, Dinobryon bavaricum Imhof, D. sociale v. Stipitatum (Stein) Lemm., Synura peterseni Korsh., Mallomonas spp. and Ochromonas spp.

Hearne Channel and Christie Bay: Cryptophytes dominated at these stations in July. Large species (Cyrptomonas ovata Ehrenb., C. rostratiformis Skuja, and C. marssoni Skuja) were most abundant in Hearne Channel while a small species (Rhodomonas lacustris) was dominant in Christie Bay. In August chrysophytes (mainly Dinobryon spp.) overtook cryptophytes in both waterbodies. Dinoflagellates were always third in importance in both places, except in August when diatoms (Synedra acus Kutz. and S. ulna (Nitzsch.) Ehrenb.) were most abundant in Hearne Channel.

McLeod Bay: Chrysophytes were always dominant in McLeod Bay. Chrysochromulina sp. (an unknown species larger than C. parva) plus Ochromonas spp. and Pseudokephyrion entzii (Conrad) Schmid. dominated in July while Chrysochromulina parva Lack., Ochromonas spp., D. sociale v. americanum (Brunnth.) Backm., D. attenuatum (Hilliard), and D. najakjaurensis Skuja were dominant in August. Cryptophytes (R. lacustris) were second in importance in July. They were replaced by various species of dinoflagellates in August. Diatoms (Cyclotella pseudostelligera Hust. and Synedra acus) regularly formed about 10% of the biomass.

Lakes surrounding Great Slave Lake

Gordon and Prosperous: Chrysophyceae dominated in Gordon and Prosperous in July. In August, chrysophytes shared dominance with dinoflagellates in Gordon and with cryptophytes in Prosperous. Prosperous had higher biomasses in July (597 $\mu g \cdot L^{-1}$) than Gordon (317 $\mu g \cdot L^{-1}$) but the two were similar in August (373 $\mu g \cdot L^{-1}$ in Gordon and 326 $\mu g \cdot L^{-1}$ in Prosperous). Chrysophyceae that were common to both lakes were Dinobryon bavaricum v. Vanhoeffenii Krieger, D. sociale Ehrenb., D. sociale v. stipitatum, Uroglena americana, C. parva, and Pseudopedinella sp., D. cylindricum Imhof and D. najakjaurensis were abundant in Gordon while D. divergens was abundant in Prosperous. In the past D. najakjaurensis has only been reported from very oligotrophic arctic and subarctic lakes. Our study bears this out as this species was present only in McLeod Bay and Gordon Lake.

Madeline: This is the smallest and shallowest of the studied lakes. Phytoplankton biomasses in this lake were the highest seen in the region (2215 $\mu g \cdot L^{-1}$ and 2609 $\mu g \cdot L^{-1}$) and it had very different species assemblages from all other studied lakes. Diatoms (Synedra spp. and Melosira spp.) and chrysophyceae (C. parva, C. punctiformis Pasch., M. pseudocoronata Prescott, and Gloeobotrys limneticus Pasch.) dominated in July. In August various species of cyanophytes (Lyngbya, Oscillatoria, Aphanizomenon, and Anabaena flos-aquae (L.) Breb.) dominated along

with the same chrysophytes (plus D. sociale) that were present in July. Although never dominant, small chlorophytes were much more abundant in this lake than in any of the other studied lakes. The species of Aphanizomenon found in Madeline Lake had been recorded previously only for lakes near Flin Flon, Manitoba and in enclosure experiments in Wupaw Bay of Southern Indian Lake (a large lake in northern Manitoba; Kling, unpublished data).

Chitty Lakes: The chrysophycean genus Dinobryon was the most important element of the phytoplankton in all of these lakes at all times. Cryptophytes were notably less abundant in these lakes than in most of the other lakes. Small Chrysophytes (Chrysochromulina parva, Pseudopedinella sp., and tiny loricate species of Chrysococcus, Kephyrion, Pseudokephyrion, Chrysolykos, and Bitrichia) also characterize these lakes.

D. bavaricum and D. sociale v. americanum dominated in Chitty Lake in July. D. sociale v. americanum dominated in August. Diatoms (Synedra spp.) were second in importance in July while the cyanophyte Aphanizomenon flos-aquae (L.) Ralfs assumed dominance in August. In Alexie Lake D. sociale v. stipitatum dominated in July while D. divergens Imhof and D. bavaricum dominated in August. Cyanophytes composed up to one-third of the biomass in July (Lyngbya limnetica) and in August (Aphanizomenon gracile Lemm.). Dinoflagellates (Peridinium aciculiferum (Lemm.) Lemm. and Gymnodinium mirable Pen.) were the third major group in this lake. Baptiste Lake showed the greatest dominance by chrysophytes (>80%) in this group of lakes. Major species here were D. sociale v. stipitatum, D. bavaricum, and D. korshikovii (Korsh.) Matv. in July, and D. divergens, and Ochromonas spp. in August. In Drygeese Lake dominant species were D. sociale v. stipitatum and Urogleena americana in July and U. americana, Ochromonas spp., and D. bavaricum in August. Small cyanophytes (Sphanotheca sp. and Cyanodictyon sp.) and small chlorophytes were second in importance in Drygeese in July. Small cryptophytes were important in August. Biomasses in these lakes ranged from 241 $\mu g \cdot L^{-1}$ to 956 $\mu g \cdot L^{-1}$ and were higher in July than in August except in Baptiste. Drygeese had the lowest biomass levels and Baptiste had the highest.

Comparison to other studies

According to Holmgren (1983) four different phytoplankton assemblages have been identified in arctic and subarctic lakes:

1. Chrysophyceae
2. Chrysophyceae-Diatom
3. Chrysophyceae-Cryptophyceae
4. Chrysophyceae-Dinophyceae

Most samples from Great Slave Lake were of the Chrysophyceae-Cryptophyceae type. However, the offshore waters in the Western Basin were dominated by diatoms and cryptophytes, a type that does not fit into Holmgren's scheme. This community is very similar to the one that occurs in the turbid southern part of Southern Indian Lake (Kling, unpublished data), a subarctic lake in northern Manitoba. In both of these waterbodies mean light levels in the mixed layers are low and algae are not severely nutrient limited.

Rawson (1956) found that the diatoms Melosira islandica, Asterionella formosa Hass., Tabellaria fenestrata (Lyngb.) Kutz., Fragellaria crotonensis Kitton, Synedra ulna, and Stephanodiscus niagarae dominated in Great Slave Lake. M. islandica was common in the turbid western basin and A. formosa in the oligotrophic eastern arm. Dinobryon divergens was the most abundant species of this genus and he noted that it was abnormally abundant in two of the nine years studied. Species composition and dry weight remained very constant from year-to-year during this period and he found that the major species in Great Slave Lake were similar to the dominant species of Lake Winnipeg and Lake Nipigon. Rawson did not find any small phytoflagellates in Great Slave Lake but this is unquestionably due to the fact that he used nets to collect samples. It is probable that the flagellates were as abundant in his time as they are now.

Lund (1962) examined plankton samples from several western Canadian lakes and found Melosira italica subsp. subarctica O. Muller and M. islandica only in Great Slave Lake. He notes that Rawson distinguished two forms of A. formosa in this lake but after considering results from a variety of lakes, he determined that they were all A. formosa. He recorded unusually long (145 µ) individuals of this species from the northern Canadian great lakes compared to the English lakes (100 µ). In our study we found specimens of A. formosa in Great Slave Lake with lengths up to 120 µ.

The phytoplankton of Madeline Lake were examined by Moore (1980b) in 1978-79. He also found that the lake was dominated by cyanophytes in late July and August. Both biomass levels and species composition in the Chitty lakes were similar to those reported by Healey and Kling (1975) for this group of lakes.

ALGAL NUTRIENT DEFICIENCY INDICATORS

Healey and Hendzel (1980) showed that the physiological state of natural algal populations is reflected in their chemical composition. From our chemical data we have calculated some of the composition ratios that they used as indicators of nutrient deficiency (particulate P/C, N/C, N/P, and chlorophyll/C) (Fig. 9). In these graphs, "Slave" refers to samples taken from the West Basin of Great Slave Lake, Yellowknife Bay, and the west end of Hearne Channel; all others are "Shield" samples. The dividing lines between regions of different degrees of nutrient deficiency are taken from Healey and Hendzel (1980) and are based on evidence drawn from laboratory cultures.

Chlorophyll/C ratios below 10 are indicative of severe but nonspecific nutrient deficiency. Most of the Shield samples demonstrated severe deficiency according to this criterion while most Slave samples were only moderately

nutrient deficient. We conclude from this that while all algal populations in this region are nutrient deficient, algae from Shield lakes are more deficient than are algae from samples influenced by Slave River waters.

The ratios of N/P and P/C are used to assess the degree of phosphorus deficiency. Neither of these indicators showed P deficiency in the majority of the Slave samples. In the Shield lakes, about half of the samples demonstrated moderate P deficiency according to the N/P ratio, and a somewhat larger fraction indicated this deficiency according to the P/C ratio. Only once did either of these indicators demonstrate severe P deficiency, a condition which is common in samples from Shield lakes located in the Experimental Lakes Area (Healey and Hendzel 1980).

Moderate nitrogen deficiency is indicated by values of the N/C ratio less than 140. Like the indicators of P deficiency, samples from the Shield lakes were consistently more deficient in nitrogen than the Slave samples.

In conclusion, the chl/C ratio showed all phytoplankton in the Yellowknife region to be nutrient deficient. Samples from Shield lakes were typically severely deficient while those influenced by Slave waters were only moderately deficient. The Shield lakes showed consistent moderate deficiencies in P and N. These deficiencies, however, were less severe than in other Shield lakes that have been studied in northwestern Ontario. Most of the samples influenced by Slave River waters demonstrated no P or N deficiency; their deficiencies are probably related to iron or trace elements (Jackson and Hecky 1980).

PRIMARY PRODUCTION

Photosynthetic parameters

A variety of methods have been devised for estimating annual phytoplankton primary production. Most of these methods require direct measurements of photosynthetic rates (with ^{14}C or O_2) at frequent time intervals throughout the year. The different methods make these measurements either *in situ* or in the laboratory, and final estimates are derived either graphically or numerically. Because specialized equipment and highly trained personnel are required, such methods are poorly suited to the needs of managers interested in using primary production as an index of the potential of a lake to produce fish.

It is possible (Fee 1984) to estimate annual primary production from data on the seasonal variations of chlorophyll concentration instead of the seasonal variations of photosynthetic rate. This method is more suited to the needs of manager because it is much easier to measure chlorophyll concentrations than to measure photosynthesis. However, production estimates given by this method are reliable only if the two parameters that are needed to convert chlorophyll concentrations into photosynthesis vs light curves are accurately known. The first of these parameters is P^B_m, the rate of carbon uptake per unit of chlorophyll at light intensities that are optimal for photosynthesis. The second parameter is α, the slope of the light limited part of the curve relating carbon uptake per unit of chlorophyll to light. If the temporal and spatial variations of these two parameters are known, then primary production can be estimated from chlorophyll concentrations with the same precision that is available from methods based on direct measurements of photosynthesis.

In practice, of course, defining the detailed variations of P^B_m and requires the same kind and number of photosynthesis measurements which the older methods required. However, during a four year period of study at the Experimental Lakes Area (ELA), the use of annual means of these parameters produced estimates of annual production within 15% of the values obtained when the detailed variations (measured every 2 weeks) of these parameters were used as input to the model (Fig. 10). Thus, if the mean annual values of these parameters could be predicted from more easily measured variables (e.g. temperature, light, and chemical composition ratios), it would be possible to estimate annual primary production from data on the seasonal variations of chlorophyll concentrations alone. It is, therefore, worth looking for patterns in the values of these parameters in different lakes.

Figure 11 shows frequency distributions of P^B_m and α in lakes of the Yellowknife region. It is clear from this figure that typical values of P^B_m from lakes located on the Canadian Shield are lower than in waterbodies influenced by the Slave River; the values of α are not different in these two types of waters. The fact that lower values of P^B_m occur in the Shield waters than in Slave waters correlates well with the differences in the nutrient deficiency indicators seen in these two types of waters (Fig. 9). Nutrient deficiencies influence P^B_m (Curl and Small 1965; Ichimura 1973; Takahaski et al. 1973; Eppley and Renger 1974; Thomas and Dodson 1972; Hecky and Guildford 1984) and in the manner seen here (more deficient populations having lower values of P^B_m). The overall similarity of α in all of these lakes indicates that the factor(s) controlling this parameter is generally similar in the entire region.

It is instructive to compare our P^B_m and α with values from other sites. The lakes chosen for this comparison were studied with the same methods that we used. They are useful for comparative purposes because they have different optical and thermal properties, and their phytoplankton populations display different degrees of nutrient deficiency.

The greatest quantity of data (n = 729) was collected from lakes in the Experimental Lakes Area (ELA) in northwestern Ontario (49°40'N, 93°54'W) during the period 1976-83. ELA lakes are small (5-50 ha) and relatively deep (up to 30 m). Surface temperatures in these lakes reach 22-24°C during midsummer and

they stratify sharply for periods of 4-5 months. ELA lakes have high transparencies (euphotic zone depths 2-3x the depth of the mixed layer in midsummer) and primary production in the mixed layers of these lakes is not light limited even in the least transparent lakes (Fee 1979). On the other hand, nutrient loading rates to ELA lakes are very low and consequently phytoplankton in the mixed layers of these lakes are severely deficient in nutrients (Healey and Hendzel 1980).

The second site chosen for comparison is Saqvaqjuac (SAQ), which is located in the Northwest Territories above treeline in a region of continuous permafrost (63°38'N, 90°40'W). Lakes in this area were studied from 1977-81, when 102 measurements of P^B_m and α were made (H. Welch, unpubl.). SAQ lakes are similar in size, depth, and geology to ELA lakes. The main differences from ELA are related to temperature: SAQ lakes have shorter ice-free seasons (3-4 months, compared to 6-7 at ELA), lower water temperatures (12-15°C midsummer maxima), and they stratify infrequently if at all. Like ELA lakes, nutrient loading rates to SAQ lakes are low and transparencies are high and consequently algae in these lakes are also nutrient and not light limited.

The last site is Southern Indian Lake (SIL), a very large (230 100 ha), shallow (10-20 m), multibasin lake located in a region of discontinuous permafrost in northern Manitoba (57°20'N, 98°20'W). SIL was studied from 1974-78 (Hecky and Guildford 1984), when 370 measurements of P^B_m and α were made. Maximum surface water temperatures at SIL (15-18°C) were intermediate between SAQ and ELA, and SIL never developed a prominent thermocline during the period for which we have P^B_m and α data. Unlike the SAQ and ELA areas, the SIL basin contains abundant glacial overburden and postglacial lacustrine deposits (Newbury et al. 1984) and nutrient loadings are thus higher in this lake. On the other hand, wind-induced resuspension of bottom sediments, the greater mixing depth, and high loading rates of inorganic materials cause mean light levels in the mixed layer of SIL (Hecky 1984) to be much lower than at the other sites (Fig. 12). Nutrients were therefore never as limiting to SIL algal populations as at ELA (Healey and Hendzel 1980; Planas and Hecky 1984) and phytoplankton in SIL were typically light limited (Hecky and Guildford 1984).

Figure 13 compares the values of P^B_m and α observed at Yellowknife with the values of these parameters at ELA, SAQ, and SIL. The Yellowknife curves fall to zero frequencies at notably lower parameter values than at any of the other sites. This is probably related to the fact that all of the Yellowknife data were collected during the summer of a single year. At the other sites measurements were made over periods of up to nine years, and are therefore influenced by interannual variability. Apart from this, there are consistent patterns in these data. All lakes where phytoplankton are nutrient deficient (ELA, SAQ, and the Yellowknife lakes) had similar frequency distributions of the photosynthetic parameters. SIL, the only lake in which phytoplankton were limited by light and not nutrients, had higher values of both P^B_m and α than the other lakes.

Nutrients and light thus seem to be primary variables controlling P^B_m and α in lakes. Studies based primarily on laboratory results (Talling 1957; Eppley 1972) have emphasized the importance of temperature in determining P^B_m. However, Fig. 13 shows that P^B_m values were similar at SAQ and ELA, the two sites with the greatest differences in temperature, while SIL, where temperatures were intermediate between SAQ and ELA, had higher values of P^B_m than at either of these sites. This indicates that, in whole lakes, algal communities can adapt more readily to lower temperatures than to insufficient nutrients or light.

Hecky and Guildford (1984) concluded from the results of the SIL study that available light is the primary variable determining α. The Yellowknife data support this conclusion as there were no differences in the values of α in the Slave and Shield waters (Fig. 11) nor in available light in these two types of waters (Fig. 12).

It would appear, then, that there are predictable patterns of variation of the photosynthetic parameters. Nutrient limited phytoplankton have lower values of P^B_m than do phytoplankton from lakes where nutrients are not limiting, and phytoplankton from lakes in which light is limiting have higher values of α than do phytoplankton from lakes where light is not limiting.

If these relationships prove to be general and the mean annual values of the photosynthetic parameters could be determined from transparency, mixing depth, and nutrient composition data, production could then be estimated from data on the seasonal changes of chlorophyll concentrations and transparency. Ultimately, it may prove possible to use aircraft or satellites to gather the required chlorophyll and transparency data, thus enabling primary production to be calculated for whole lake districts on a routine basis.

Early attempts to estimate primary production from chlorophyll and transparency data (e.g. Ryther and Yentsch (1957)) were never widely adopted. They failed because they oversimplified the problem by assuming that P^B_m and α were constant in all waterbodies, and by using an analytically imprecise method to integrate the photosynthesis curve. The new approach described here treats these factors realistically and promises to be an important tool for managing fish populations.

Annual production estimates

In order to estimate annual phytoplankton production rates the data, which are available for the period mid-June to mid-August, must be extrapolated to the period mid-June to mid-November. This would normally be unwarranted but since one of the purposes of this work was to demonstrate the potential utility of primary

productivity data as an index of the potential of a lake to produce fish, it is worth making such an extrapolation, recognizing that the annual production estimates contain more than the usual amount of uncertainty.

Annual integral productivities were approximated by assuming that production for the period from 20 June to 15 August is between one-third and one-half of the annual total. These fractions are slightly greater than the ratio between the period of study and the length of the ice-free season because the period of study includes the warmest months and longest days. A further implicit assumption (since only an integral epilimnion water sample was analyzed at each station) is that the photosynthetic properties of the mixed layer extend throughout the euphotic zone. This was usually the case. However, McLeod and Christie Bays in August had mixed depths of 8 and 3 m, respectively, while the depths of 1% of surface light were 27 and 12 m, respectively. Because of the assumptions that had to be made to derive the production rates given in Table 7, these values should be considered to be only rough approximations. The value for the inshore West Basin of Great Slave Lake was derived from data at Kam Point (location 6 in Yellowknife Bay); see the section Chemical composition of individual lakes for the rationale of this assumption.

Yellowknife Bay, which receives effluents from the city of Yellowknife, had the highest production rates. Note that while on a per square meter basis this bay was only 2-3 times more productive than lakes with the lowest productivities, on a per cubic meter basis it was 4-7 times more productive. This again demonstrates how the deep euphotic zones (Appendix 4) of oligotrophic lakes (e.g. Christie and McLeod Bays) compensate for their low productivities per unit volume (Fee 1979).

All of these lakes have low annual productivities compared to more southerly lakes (see Vollenweider et al. (1974) for a summary of productivity of the Laurentian Great Lakes, and Fee et al. (1982) for a summary of productivities of ELA lakes). This is largely due to their shorter open water season. This conclusion follows from the fact that chlorophyll concentrations and the photosynthetic efficiencies of a unit of chloropyll (as measured by the parameters P^B_m and α) in the Yellowknife region are similar to those occurring in more southerly latitudes.

The data in Table 7 show that production was positively correlated with suspended phosphorus and nitrogen concentrations but not with the concentrations of the dissolved forms of these nutrients nor with any of the major ions (all of which varied in the same way that conductivity did). These relationships are most clearly demonstrated by comparing Christie Bay with McLeod Bay. These bays had very different major ion concentrations but similar nutrient concentrations and the same productivity.

Methods

The design of the photosynthesis incubator could be improved. The device used in this study provided replicate photosynthesis estimates at four or five light levels. This does not give as much useful information for calculation of photosynthetic parameters (P^B_m and α) as would data at eight or 10 light levels without replication. The current incubator is also cumbersome to transport and requires a lot of laboratory space.

The two kinds of scintillation vials used in this study (glass and plastic) gave significantly different results. Samples processed in plastic vials had unacceptably high and variable background counts and photosynthesis parameters could not be calculated for the experiments where they were employed (sta. 32-44). The problem appears to be due to adsorption of inorganic ^{14}C to the plastic (Sondergaard 1980). Even prolonged and vigorous bubbling in an acid environment did not remove all of this adsorbed ^{14}C. Parallel measurements on identical samples made in glass vials did not have this problem. We recommend that glass vials be used if ^{14}C is going to be removed from the sample by bubbling in the vial.

RELATION OF FISH YIELDS TO PRIMARY PRODUCTION

One of the purposes of this work was to demonstrate the potential utility of information on phytoplankton primary production for managing fish populations in northern lakes. Unfortunately, the available information on both fish yields and primary production for lakes in the Yellowknife region is inadequate to allow more than a general introduction to some of the possibilities for future work on this important subject. In what follows, fish yields have been converted from units of wet weight to dry weight of carbon by multiplying by 0.1 (Oglesby 1977).

The only lakes that we studied for which fish harvest data are available (commercial catch records, Department of Fisheries and Oceans, Winnipeg) are the West Basin of Great Slave Lake and the Chitty lakes. Figure 14 shows how fish harvests and primary productivities from these lakes compare with results from other north temperate zone lakes (Oglesby 1977). All of the Yellowknife lakes had greater fish yields than Oglesby's regression line would have predicted from their annual primary productivities. In the case of the Chitty lakes, this is explicable. Fish yields from these lakes were not the result of a normal commercial fishery. Rather, as part of an experiment designed to discover how fish populations respond to exploitation, these lakes were deliberately overfished (Healey 1980). Further, Oglesby excluded from his regression analysis all data from lakes smaller than 10 km^2 because he found that small lakes were exploited more efficiently than large lakes. All of the Chitty lakes are smaller than 10 km^2 and would thus be expected to have higher yields for their primary productivities than the larger lakes included in Oglesby's figure. Indeed, the ratios between fish yields and primary production in the Chitty lakes are similar to ratios from several small lakes that Oglesby excluded from his statistical analysis.

Commercial harvests of fish from the West Basin of Great Slave Lake (0.7 $kg \cdot ha^{-1} \cdot yr^{-1}$, wet weight) are five to 10 times higher than Oglesby's regression line would predict for its level of primary production. If our results are accurate, this indicates that either the lake is being overfished, or energy transfers in its food chains are unusually efficient. We know of no reasons why this lake would be more efficient at transferring energy from phytoplankton to fish than the lakes analyzed by Oglesby. However, we cannot conclude that the lake is being overfished because there are good reasons to believe that our primary production estimate for the West Basin is low. The data from which we derived our estimate were obtained from a station located on the north edge of the lake. The major nutrient sources to the West Basin are rivers that enter the southern edge of the lake. It is likely, therefore, that annual primary production rates for that region in particular and probably for the lake as a whole are higher than the value we obtained. Further, these rivers supply large quantities of dissolved and particulate organic carbon which may provide additional food energy to the aquatic food chains in the West Basin. These problems are not likely to influence our estimates of production in the other large lakes that we studied because these lakes do not receive similar inflows and we sampled their offshore waters.

Based on their annual primary productivities, Oglesby's regression line predicts fish yields of 0.0002 g $C \cdot m^{-2} \cdot yr^{-1}$ for Gordon Lake, McLeod Bay and Christie Bay. This figure is 1/30th of current harvest from the West Basin of Great Slave Lake and strongly supports the prohibition of commercial fishing on these waterbodies. The predicted value for Prosperous Lake is 0.001 g $C \cdot m^{-2} \cdot yr^{-1}$, which is 1/7th of the current West Basin harvest.

CONCLUSIONS

Trophic dynamic theory and observations from other geographic regions lead us to conclude that the low annual primary productivities of lakes in the Yellowknife region set rigid limits on the quantities of fish that can be harvested from these lakes on a sustained basis. Quantitative analysis of this important subject is currently hampered by inadequate data - our annual primary production values are based on too short of a period of observation, and there are too few data on sustained fish yields from northern lakes. More information on both fish yields and primary productivities of northern lakes is needed before final conclusions can be drawn about the practical utility of using primary production data to manage fish populations. The work reported here has shown that presently available analytical tools are adequate for gathering the required primary production data.

To date, little use has been made of modern trophic-dynamic theories in fisheries management problems. If consistent relations are found between fish yields and annual primary production in northern lakes, the ability to predict the values of the parameters of primary production models (Fig. 9) from phytoplankton nutrient deficiency indicators may prove to be the key that will allow primary productivities of lakes of this region to be monitored from information on their chlorophyll concentrations and transparencies. Both chlorophyll and transparency are easy to measure, and the possibility even exists that they can be monitored with sensors mounted in satellites or aircraft. We are clearly just beginning to appreciate how such tools will change the nature of fisheries research and management in the decades ahead.

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Table 1. Summary of some morphometric features of the studied lakes.

Lake	Surface area (ha)	Maximum depth (m)
Madeline	110	9
Chitty lakes	305-547	20-35
Prosperous	3 320	89
Gordon	18 420	≈100
Great Slave Lake		
Yellowknife Bay	3 200	2-60
West Basin	1 940 000	165
Hearne Channel	229 000	320
Christie Bay	212 000	625
McLeod Bay	159 000	293

Table 2. Measured and calculated specific conductances (means for all stations in each lake). Units are $\mu S \cdot cm^{-1}$.

Lake	Measured Conductance	Calculated Conductance
Alexie Lake	120	120
Baptiste Lake	120	125
Chitty Lake	113	117
Gordon Lake	80	82
Madeline Lake	285	342
Drygeese Lake	120	122
Christie Bay	183	197
Hearne Channel	193	212
McLeod Bay	30	31
Propserous Lake	50	48
GSL West Basin	213	220
Yellowknife Bay location 1	160	189

$n = 12$

$r = 0.994$

$y = 1.18x - 13$

Table 3. Summary of conductivities, maximum temperatures, and Secchi disk depths in the sampled waterbodies. Units: conductivity - $\mu s \cdot cm^{-1}$, temperature - °C, Secchi - metres.

Water Body	Conductivity Mean	Conductivity Range	Maximum Temp	Maximum Secchi
McLeod Bay	30	0	11.3	9.8
Prosperous	50	0	17.4	5.5
Gordon	80	0	16.8	9.8
Chitty Lakes	115	10	18.1	8.0
Yellowknife Bay	163	120	18.6	3.8
Christie Bay	185	10	12.3	12.7
Hearne Channel	193	20	11.3	6.0
West Basin of GSL (inshore)	213	30	16.0	3.8
Madeline Lake	285	10	18.6	2.4

Table 4. Comparison of mean chemical and physical properties of McLeod Bay, Christie Bay and the West Basin of Great Slave Lake. For the latter, means of the values at the Kam Point station in Yellowknife Bay were used since this is the only station that reflects seasonal changes. The units for conductivity are $\mu S \cdot cm^{-1}$, for the in situ extinction coefficient are per m, for maximum temperature are °C, for SiO_2 are $mg \cdot L^{-1}$ and for the other chemical constituents are $\mu moles \cdot L^{-1}$.

Water Body	Cond.	Ext. coef.	Max. temp.	Alk.	Cl	SO_4	Na	Ca	Mg	SiO_2
McLeod Bay	30	0.19	9.8	188	40	23	44	74	42	0.22
Christie Bay	185	0.31	10.0	1365	233	198	262	547	207	1.37
West Basin	215	0.57	16.0	1496	212	194	287	610	225	1.22

Table 5. Comparison of chemical data from this work with the 1971 results of Brunskill (185) and the 1972 results of Healey and Woodall (1973).

Lake	Year	Cond. $\mu s \cdot cm^{-1}$	pH	HCO_3^{-1} $\mu Eq \cdot L^{-1}$	SiO_2 $\mu g \cdot L^{-1}$	TDP $\mu g \cdot L^{-1}$	TDN $\mu g \cdot L^{-1}$	Ca $mg \cdot L^{-1}$	Mg $mg \cdot L^{-1}$	Na $mg \cdot L^{-1}$	K $mg \cdot L^{-1}$
Prosperous	1971	130	7.1	300							
	1983	50	7.5	260							
Chitty	1971	84	7.5	970	150	16	530	14	6.1	3.7	2.2
	1972	110	7.6	890	120	15	500	12	8.7	3.5	2.2
	1983	110	8.0	780	100	7	500	10	4.9	3.9	2.3
Baptiste	1971	65	7.0	900	470	15	300	12	5.8	3.3	2.2
	1972	118	7.4	890	440	15	380	12	5.5	3.4	2.3
	1983	120	7.9	800	360	6	350	12	4.4	4.1	2.3
Alexie	1971	35	7.5	930	230	17	490	12	5.6	3.8	2.0
	1972	115	7.6	910	222	17	490	12	5.7	3.3	2.2
	1983	120	8.0	780	190	7	440	11	5.1	3.5	2.3
Drygeese	1971	95	7.4	840	890	18	300	11	5.5	3.8	2.2
	1972	120	7.5	850	780	22	420	12	5.4	3.7	2.2
	1983	120	7.9	730	640	6	280	11	4.4	3.9	2.1

Table 6. Mean phytoplankton biomass and mean percent compositions of phytoplankton in the studied lakes. The abbreviations for percent composition are: Cya = cyanophyceae, Chl = chlorophyceae, Eug = euglenophyceae, Chr = chrysophyceae, Dia = diatomeae, Cry = cryptophyceae, Per = peridineae.

	Biomass	Percent composition						
	$mg \cdot m^{-3}$	Cya	Chl	Eug	Chr	Dia	Cry	Per
McLeod Bay	135	0	2	0	49	5	25	20
Gordon Lake	345	2	3	0	63	8	8	16
Christie Bay	396	0	3	0	47	4	37	9
GSL West Basin (offshore)	423	0	5	0	11	48	21	15
Hearne Channel	441	0	1	0	48	4	40	7
Prosperous Lake	462	0	0	0	64	1	22	12
Chitty Lakes	510	11	5	1	62	7	7	9
GSL West Basin (inshore)	656	1	1	0	58	11	26	3
Madeline Lake	2412	39	10	0	15	26	8	2

Table 7. Annual primary productivities and means of chlorophyll, conductivity and nutrients in the studied lakes. The units for chlorophyll are $mg \cdot m^{-3}$ and for conductivity $\mu s \cdot cm^{-1}$.

Water Body	Production $g\ C \cdot yr^{-1}$ m^{-2}	Production $g\ C \cdot yr^{-1}$ m^{-3}	Chl	Nutrient concentrations $\mu moles \cdot L^{-1}$ Cond.	TDP	Susp-P	TDN	Susp-N
McLeod Bay	15	0.6	1.2	30	6.5	1.9	290	17
Gordon Lake	15	0.9	1.1	80	9.0	2.8	270	26
Christie Bay	15	0.9	2.2	185	5.8	3.3	305	26
Chitty Lakes	20	1.2	1.3	115	6.3	3.4	373	30
Hearne Channel	20	1.5	2.3	190	7.5	3.6	328	25
Prosperous Lake	30	2.4	2.8	50	6.0	4.2	277	35
West Basin (inshore)	30	3.0	2.7	215	7.3	5.2	291	59
Yellowknife Bay	40	4.0	3.9	145	8.5	6.5	325	45

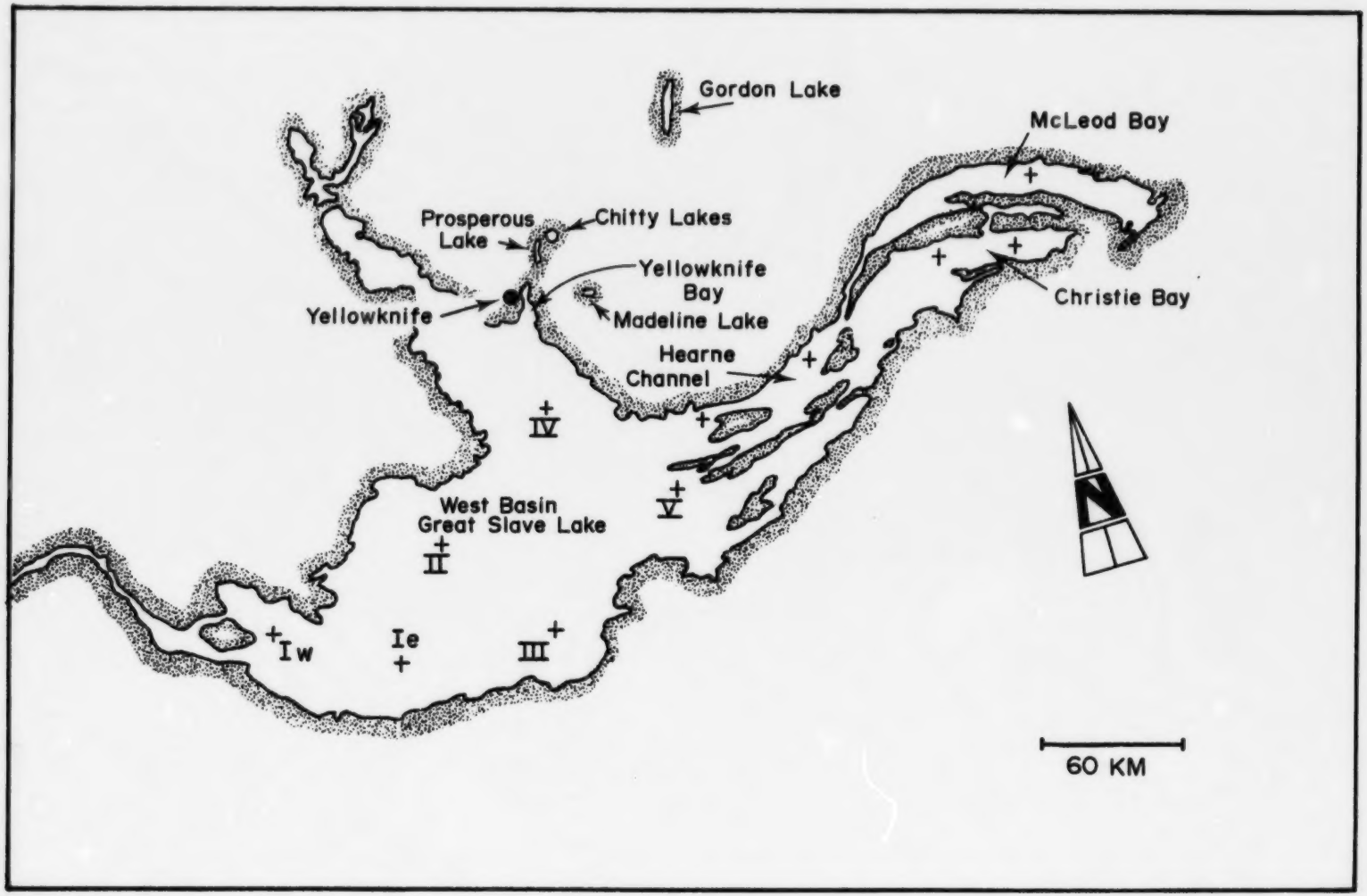

Fig. 1. Map of the Yellowknife area showing the locations and sizes of the studied lakes. Plus signs mark the location of sampling stations on Great Slave Lake. Roman numerals refer to fishing quota areas and are used to differentiate sampling stations in the West Basin.

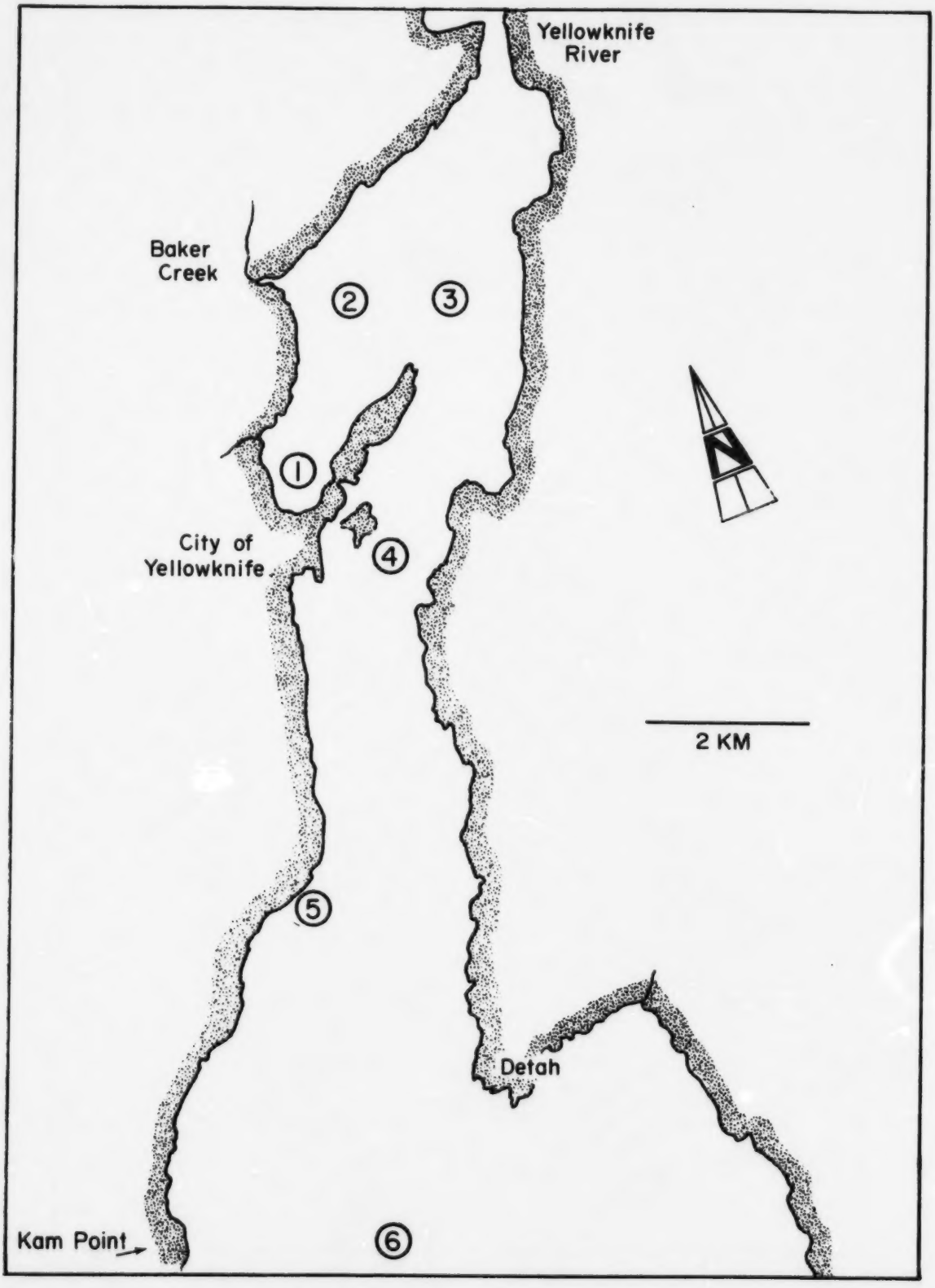

Fig. 2. Map of Yellowknife Bay showing the locations of the sampling stations.

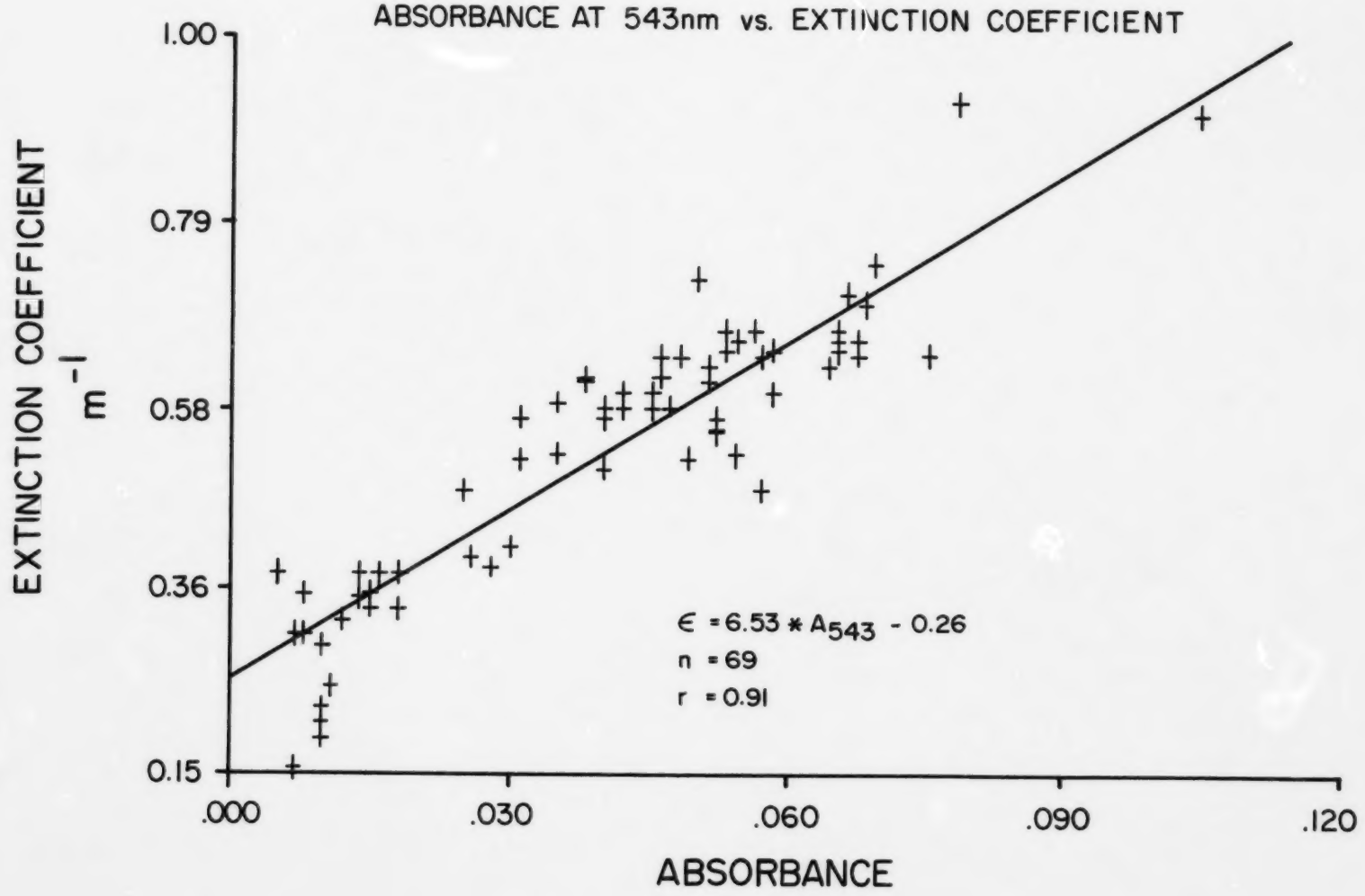

Fig. 3. The relation between absorbance at 543nm and the <u>in situ</u> extinction coefficient.

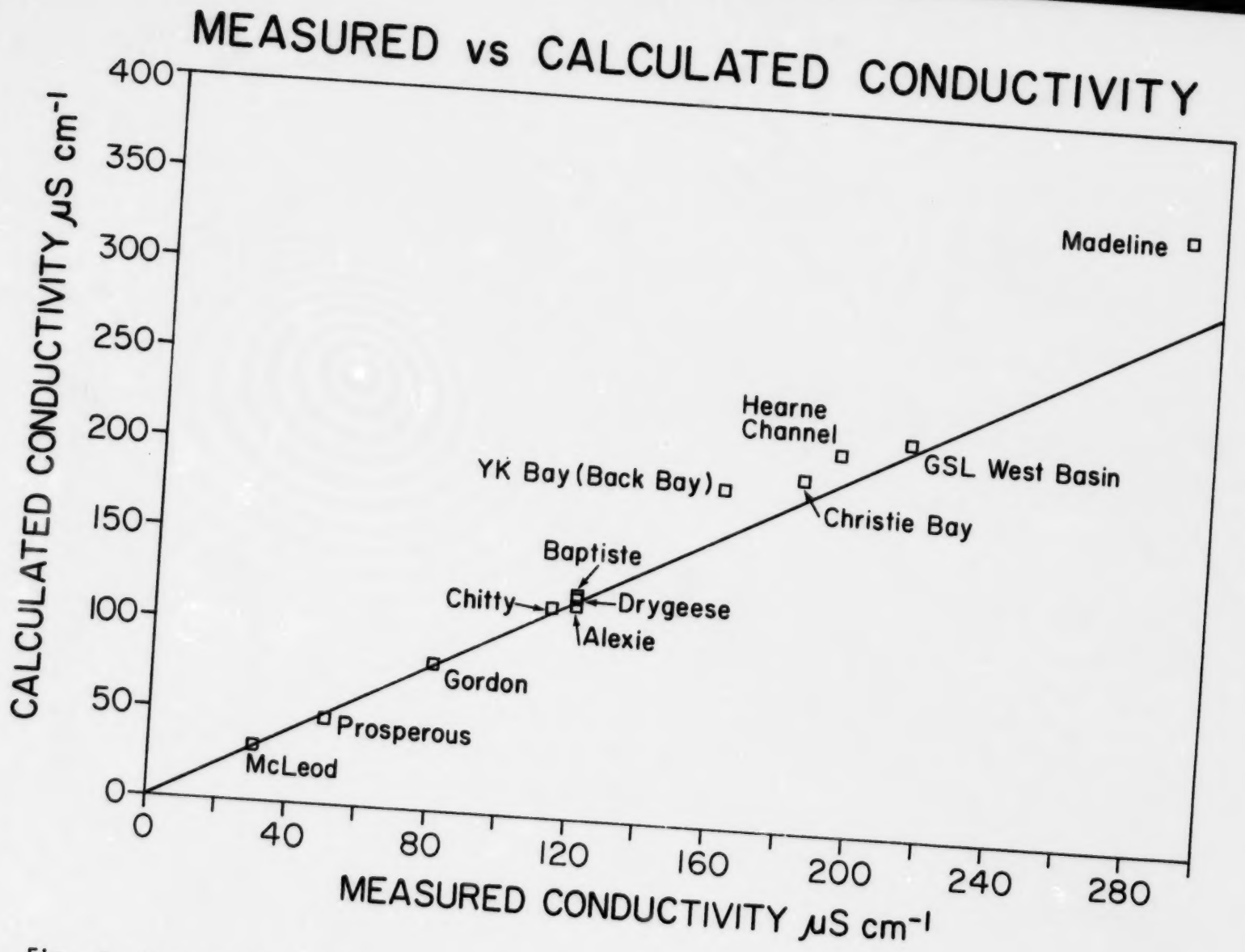

Fig. 4. Measured vs calculated conductivity for all waterbodies (mean values). A 1:1 line (perfect agreement) is drawn on for reference.

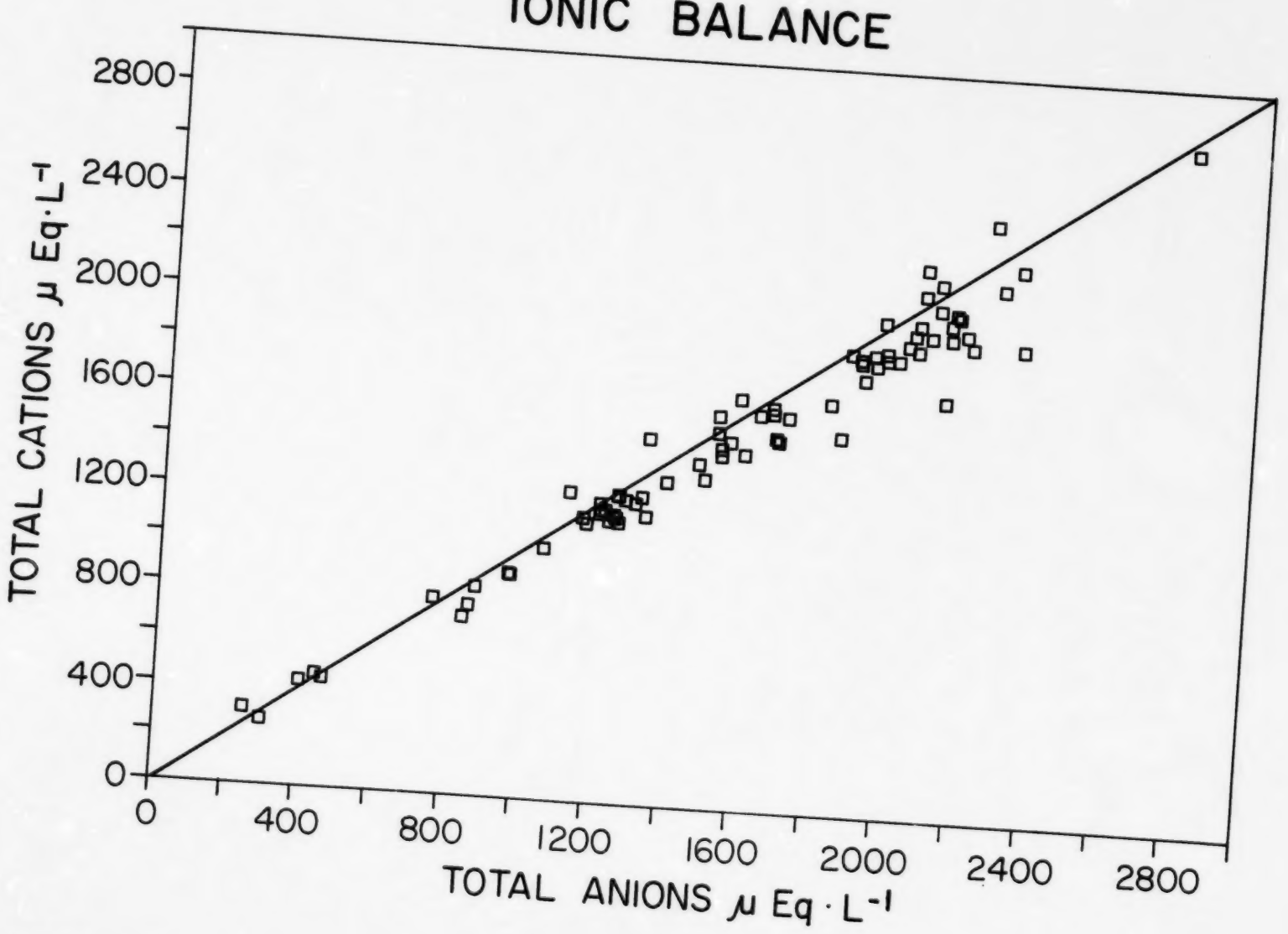

Fig. 5. Calculated total anions vs total cations. A 1:1 line (perfect agreement) is drawn on for reference.

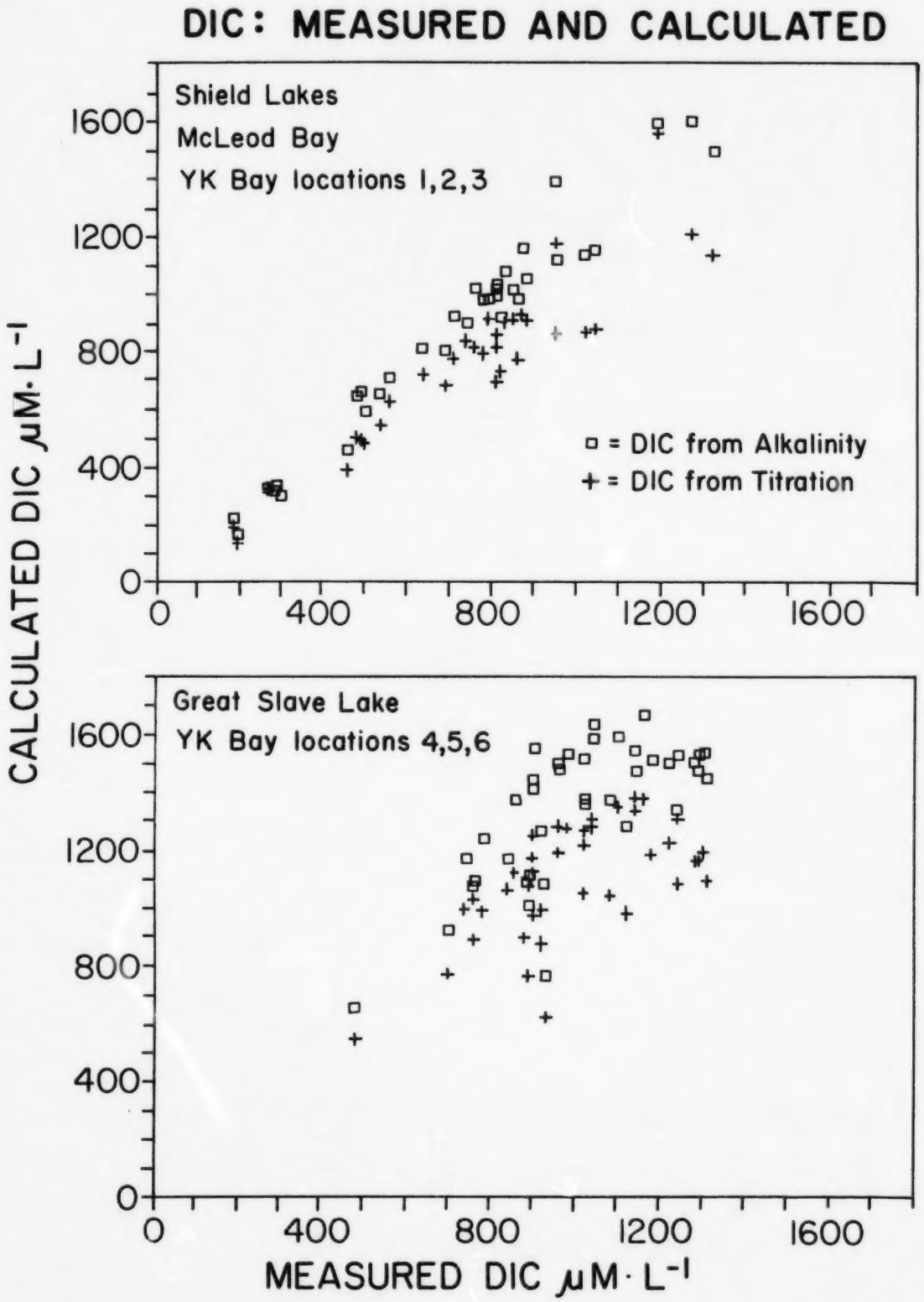

Fig. 6. Calculated vs measured dissolved inorganic carbon concentrations. The top panel gives the data for the stations where Shield waters dominate, the lower panel for stations where Slave waters dominate. A 1:1 line (perfect agreement) is drawn on for reference.

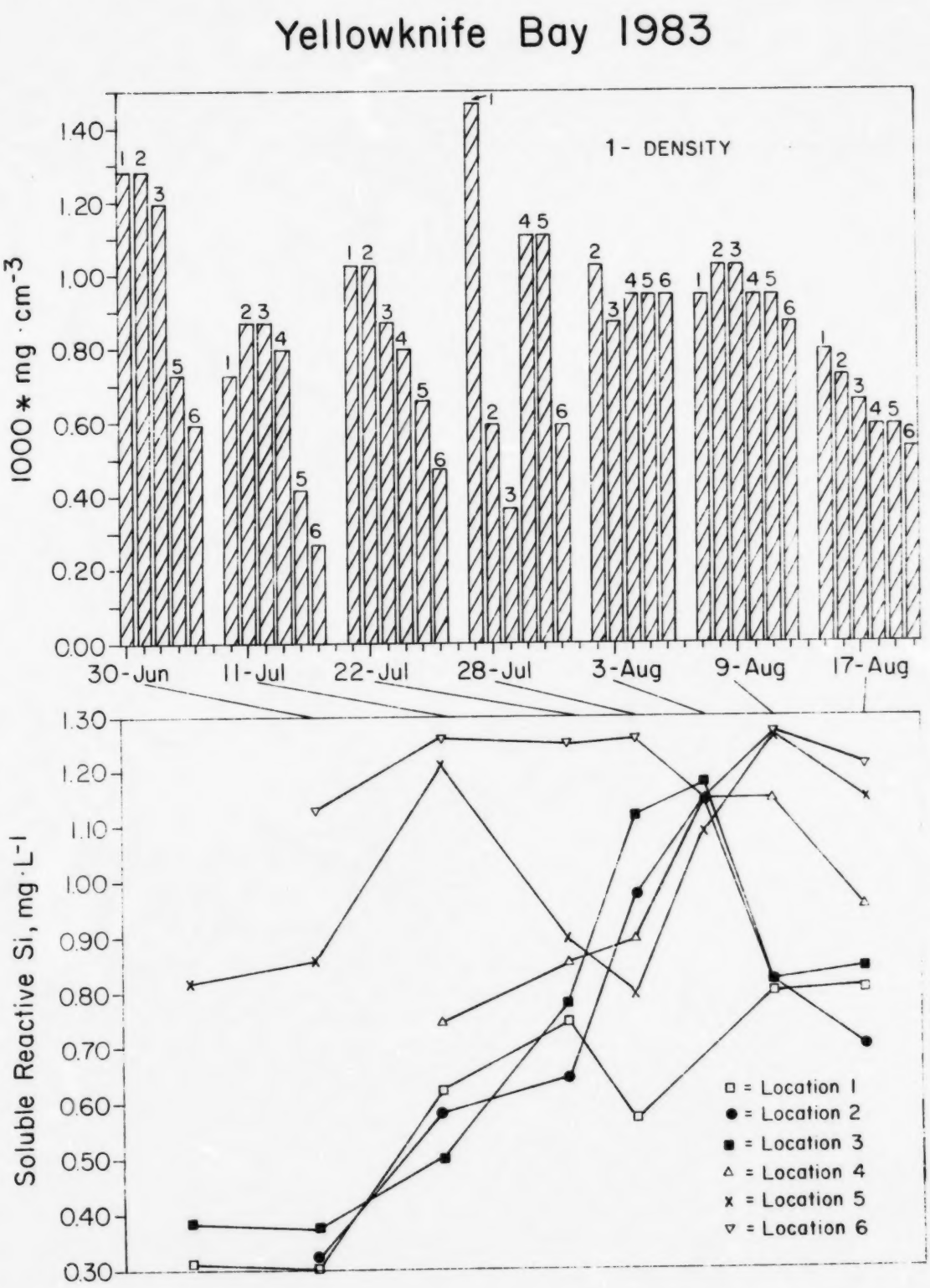

Fig. 7. Density anomalies and silica concentrations in Yellowknife Bay. Anomalies are expressed as the difference between the actual density and maximum density (i.e. samples with low values have high densities). The numbers refer to the station locations in Figure 2.

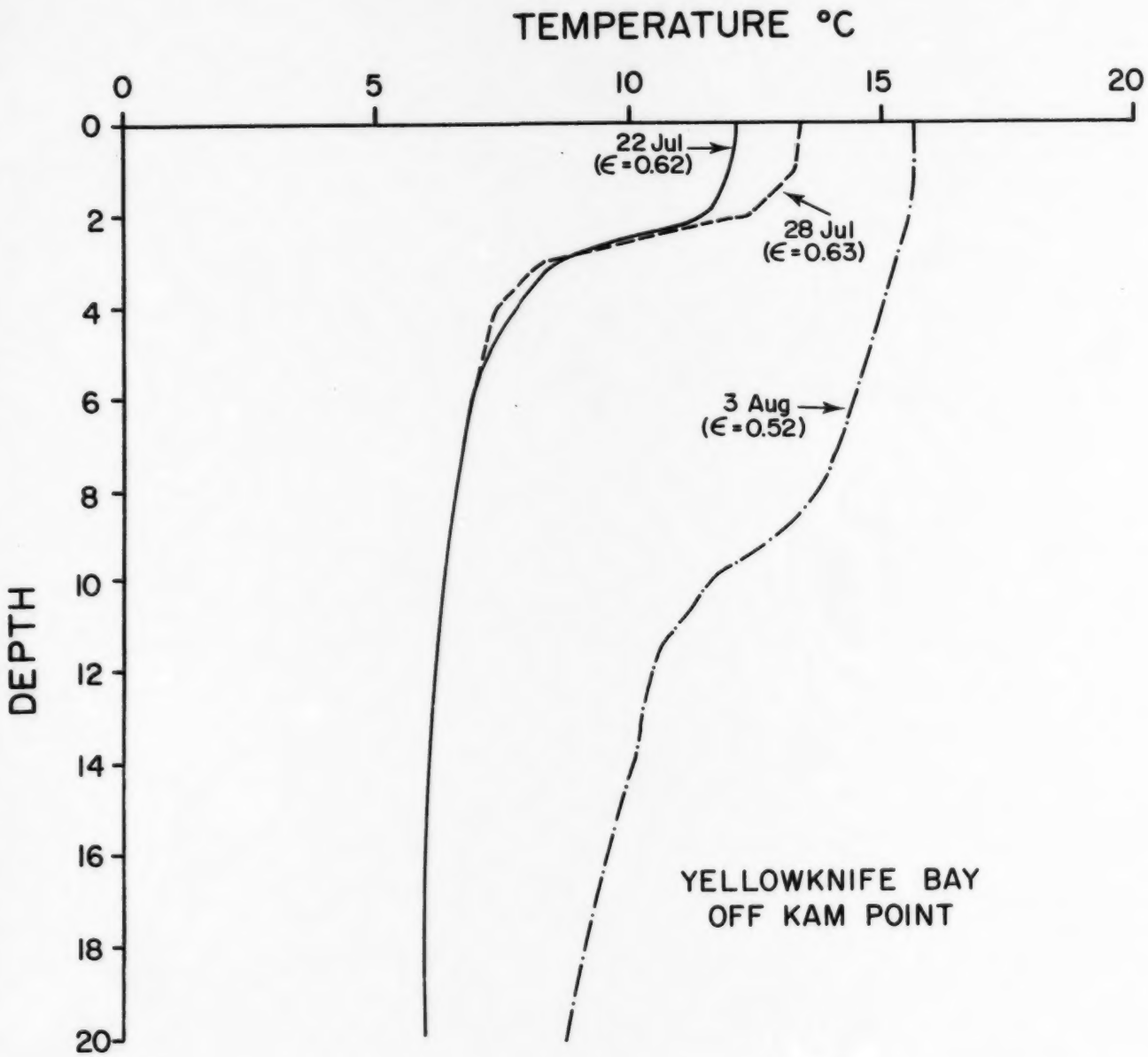

Fig. 8. Temperature profiles and in situ extinction coefficients at Kam Point (Yellowknife Bay) at 6 day intervals.

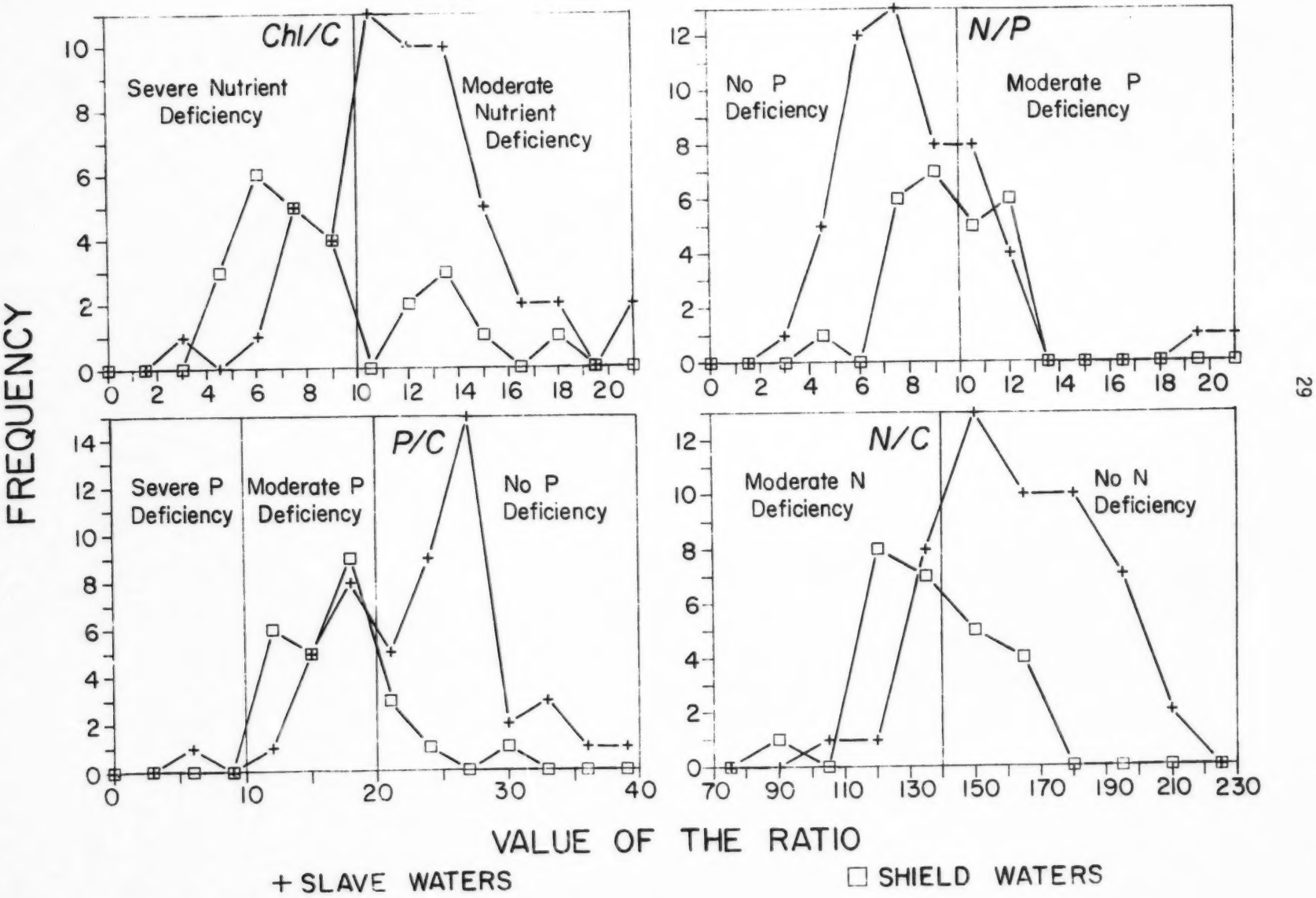

Fig. 9. Nutrient deficiency indicators. The units are micrograms particulate P, N and chlorophyll per mg particulate C, and micrograms particulate N per microgram particulate P.

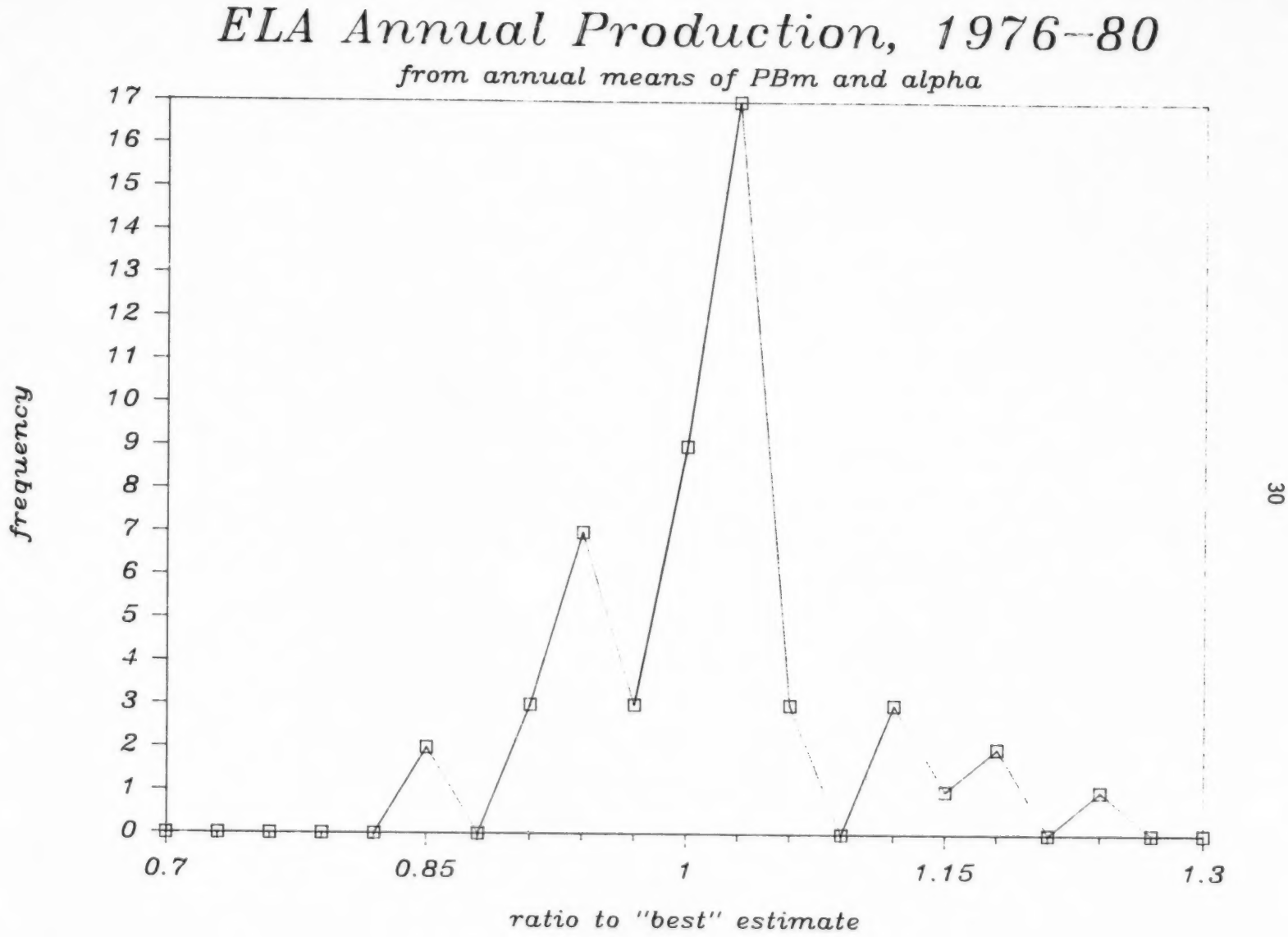

Fig. 10. Frequency distributions of errors in annual production estimates that result from using annual means of the photosynthesis parameters instead of biweekly measurements.

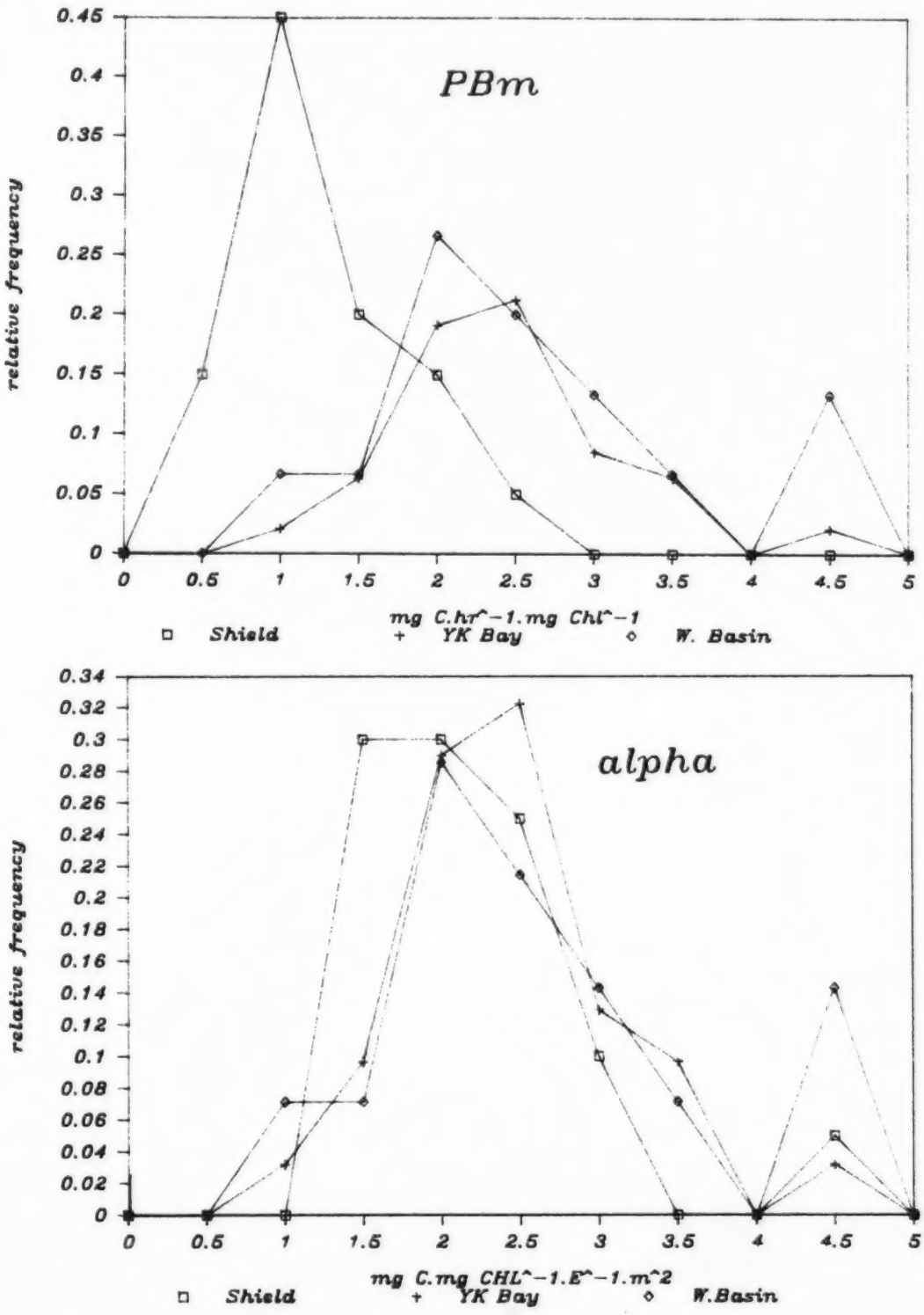

Fig. 11. Frequency distributions of photosynthetic parameters in lakes of the Yellowknife region.

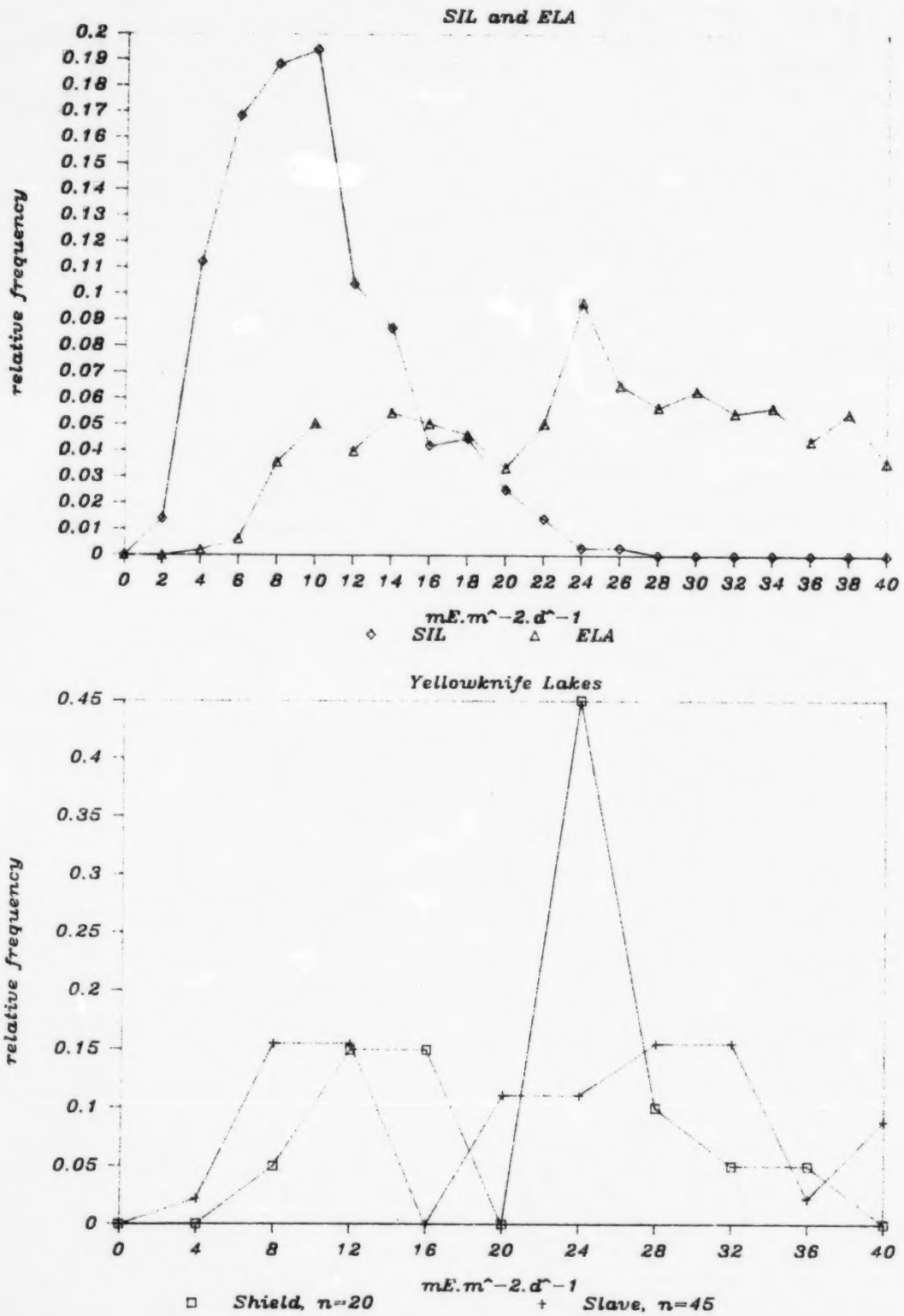

Fig. 12. Frequency distributions of mean available light in the water column in ELA, SIL and the Yellowknife lakes.

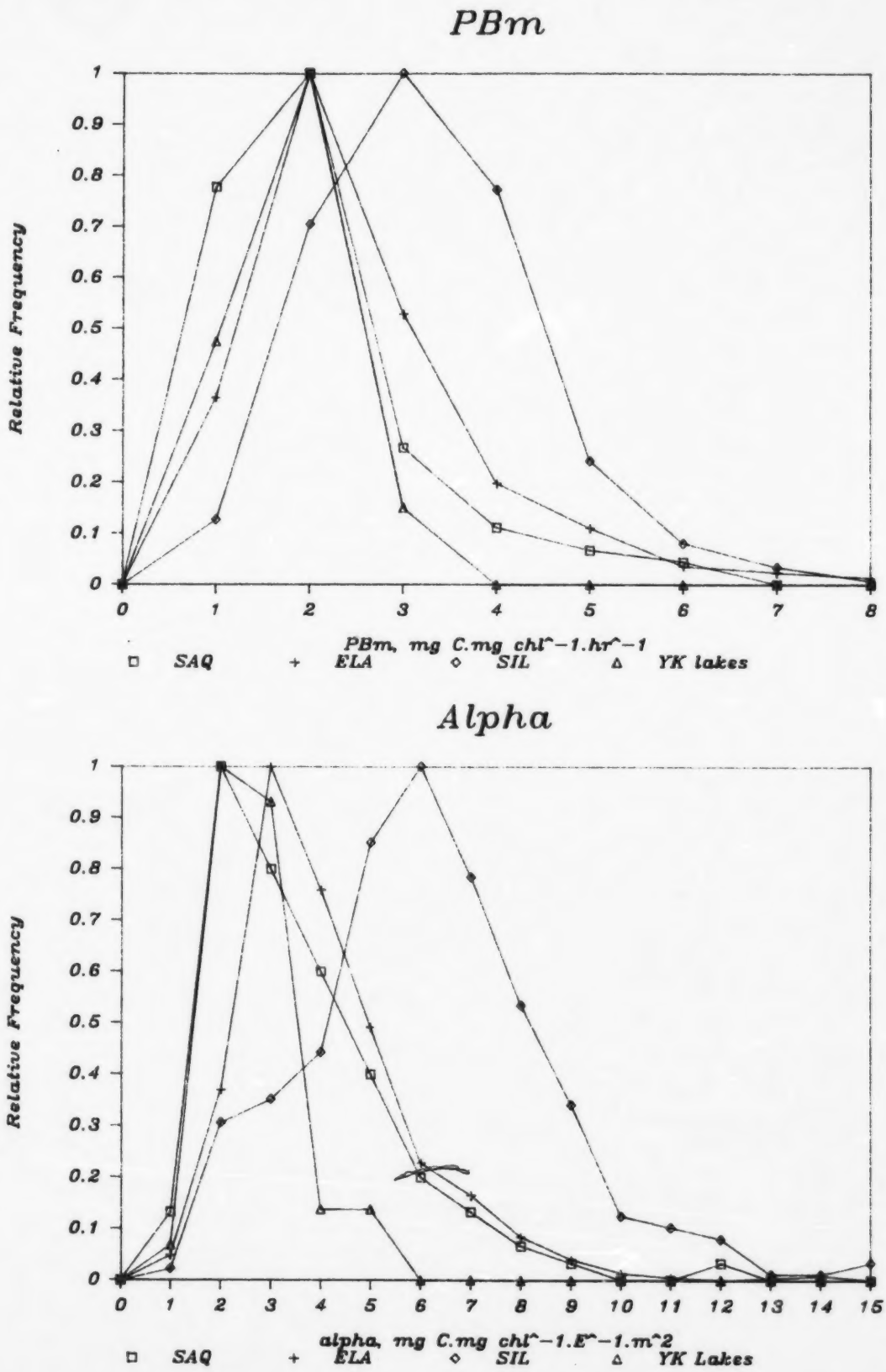

Fig. 13. Comparison of the frequency distributions of photosynthetic parameters in the Yellowknife area with values from ELA, SIL and SAQ.

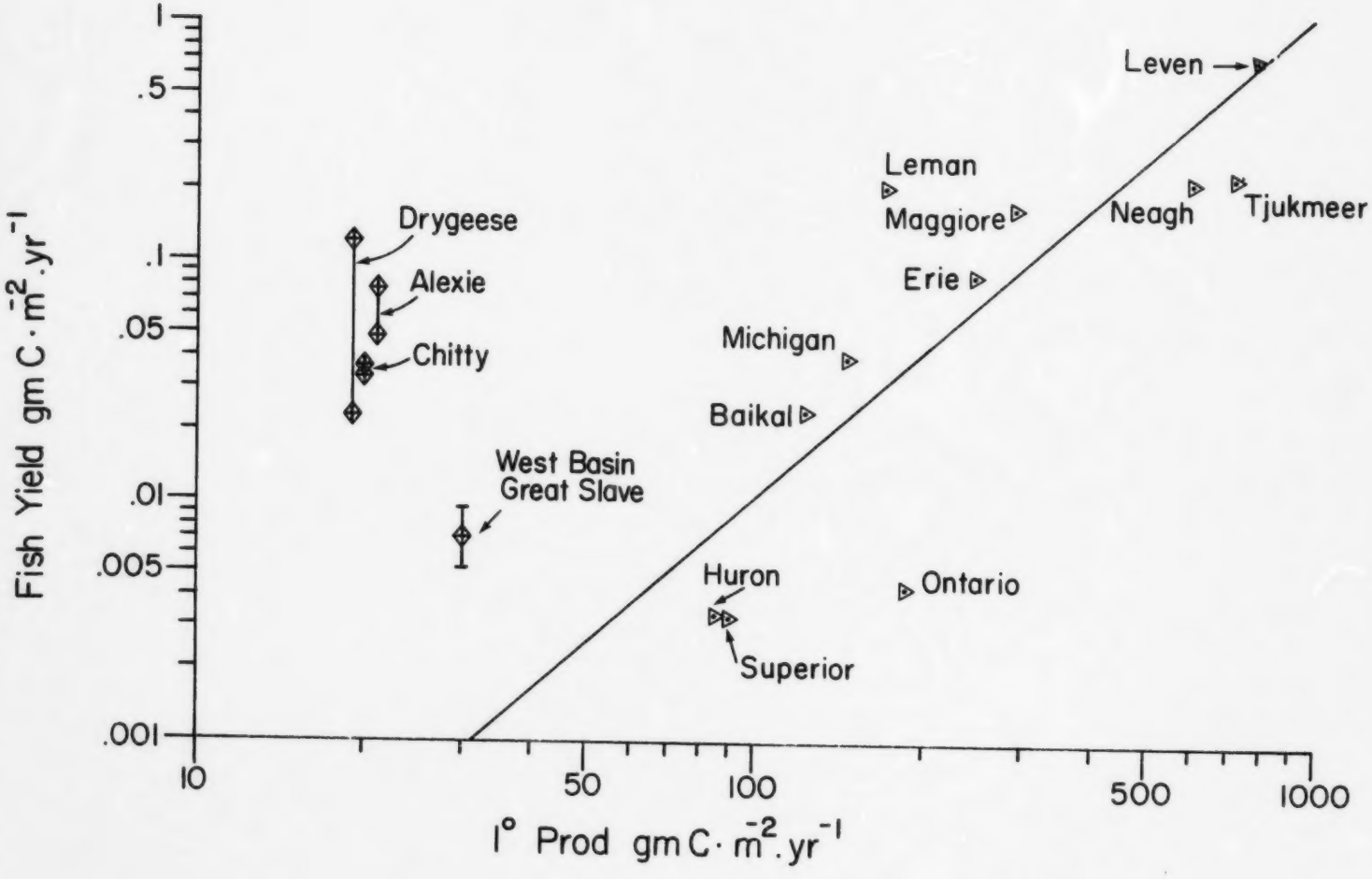

Fig. 14. Relation of fish yield to annual primary production for north temperate zone waterbodies.

Appendix 1. Station list, giving sampling locations, times, temperatures at the time of sampling and in the incubator and the depth range that was integrated. GSL = Great Slave Lake, YKB = Yellowknife Bay, NA = data not available. The column labelled "Loc" gives station location abbreviations used in the other appendices.

Sta	Loc	Location	Sample Date	Sample Time	Temperature Field	Temperature Incub	Depths Sampled
1	YK1	YKB location 1	19-Jun	08:30	8.9	7.5	0-2
2	YK3	YKB location 3	19-Jun	09:05	6.5	7.5	0-4
3	YK5	YKB location 5	19-Jun	09:45	NA	7.5	0-5
4	ALX	Alexie Lake	22-Jun	08:00	12.7	11.0	0-4
5	CHI	Chitty Lake	22-Jun	08:30	14.6	11.0	0-4
6	DRY	Drygeese Lake	22-Jun	08:55	12.1	11.0	0-4
7	BAP	Baptiste Lake	22-Jun	09:16	12.9	11.0	0-5
8	PRO	Prosperous Lake	22-Jun	09:40	7.3	11.0	0-10
9	W2	GSL, W. Basin, Area II	27-Jun	07:30	8.6	7.0	0-8
10	W1W	GSL, W. Basin, Area I W.	27-Jun	08:20	9.6	7.0	0-7
11	W1E	GSL, W. Basin, Area I E.	27-Jun	08:45	8.1	7.0	0-5
12	W3	GSL, W. Basin, Area III	27-Jun	09:10	8.5	7.0	0-2.5
13	W5	GSL, W. Basin, Area V	27-Jun	09:45	7.4	7.0	0-3
14	W4	GSL, W. Basin, Area IV	27-Jun	10:23	6.8	7.0	0-5
15	YK6	YKB location 6	30-Jun	07:51	13.1	15.0	0-2.5
16	YK5	YKB location 5	30-Jun	08:25	14.2	15.0	0-4
17	YK3	YKB location 3	30-Jun	09:07	17.4	15.0	0-4
18	YK2	YKB location 2	30-Jun	09:38	17.7	15.0	0-3.5
19	YK1	YKB location 1	30-Jun	09:56	17.8	15.0	0-2
20	HCW	GSL, Hearne Channel W.	05-Jul	06:48	5.0	4.5	0-7
21	HCE	GSL, Hearne Channel E.	05-Jul	07:20	6.1	4.5	0-10
22	CBW	GSL, Christie Bay W.	05-Jul	07:52	4.3	4.5	0-20
23	CBE	GSL, Christie Bay E.	05-Jul	08:21	4.2	4.5	0-20
24	MCL	GSL, McLeod Bay	05-Jul	08:54	4.2	4.5	0-20
25	GOR	Gordon Lake	05-Jul	10:07	13.1	4.5	0-7
26	YK6	YKB location 6	11-Jul	08:10	10.1	12.0	0-10
27	YK5	YKB location 5	11-Jul	09:48	11.6	12.0	0-8
28	YK4	YKB location 4	11-Jul	09:20	14.6	12.0	0-5
29	YK3	YKB location 3	11-Jul	09:50	15.4	12.0	0-3.5
30	YK2	YKB location 2	11-Jul	10:11	15.2	12.0	0-4
31	YK1	YKB location 1	11-Jul	10:30	14.3	12.0	0-2
32	PRO	Prosperous Lake	13-Jul	06:56	16.0	16.5	0-5
33	BAP	Baptiste Lake	13-Jul	07:17	17.0	16.5	0-5
34	DRY	Drygeese Lake	13-Jul	07:48	16.7	16.5	0-5
35	CHI	Chitty Lake	13-Jul	08:10	17.9	16.5	0-5
36	ALX	Alexie Lake	13-Jul	08:37	17.2	16.5	0-5
37	MAD	Madeline Lake	13-Jul	09:13	18.9	16.5	0-4
38	YK4	YKB location 4	19-Jul	08:03	11.7	12.2	0-4
39	YK6	YKB location 6	22-Jul	08:25	12.1	13.5	0-3
40	YK5	YKB location 5	22-Jul	08:50	13.6	13.5	0-4
41	YK4	YKB location 4	22-Jul	09:15	14.8	13.5	0-3
42	YK3	YKB location 3	22-Jul	09:35	15.4	13.5	0-3
43	YK2	YKB location 2	22-Jul	09:51	16.3	13.5	0-3
44	YK1	YKB location 1	22-Jul	10:03	16.1	13.5	0-1.5
45	YK6	YKB location 6	28-Jul	08:45	13.4	14.5	0-3

46	YK5 YKB location 5	28-Jul	09:17	16.6	14.5	0-3
47	YK4 YKB location 4	28-Jul	09:40	16.7	14.5	0-2
48	YK3 YKB location 3	28-Jul	10:10	11.1	14.5	0-3
49	YK2 YKB location 2	28-Jul	10:26	13.3	14.5	0-3
50	YK1 YKB location 1	28-Jul	10:45	18.6	14.5	0-1.5
51	YK6 YKB location 6	03-Aug	08:40	15.8	12.5	4-10
52	YK5 YKB location 5	03-Aug	09:16	15.6	12.5	4-10
53	YK4 YKB location 4	03-Aug	09:50	15.6	12.5	3-8
54	YK3 YKB location 3	03-Aug	10:25	15.3	12.5	3-7
55	YK2 YKB location 2	03-Aug	10:45	16.0	12.5	3-7
56	PRO Prosperous Lake	05-Aug	06:50	17.4	17.5	0-7
57	BAP Baptiste Lake	05-Aug	07:15	17.9	17.5	0-6
58	DRY Drygeese Lake	05-Aug	07:42	17.8	17.5	0-6
59	CHI Chitty Lake	05-Aug	08:15	18.1	17.5	0-5
60	ALX Alexie Lake	05-Aug	08:50	17.8	17.5	0-6
61	MAD Madeline Lake	05-Aug	09:17	18.6	17.5	0-5
62	HCW GSL, Hearne Channel W.	08-Aug	06:50	11.1	11.5	0-6
63	HCE GSL, Hearne Channel E.	08-Aug	07:20	11.3	11.5	0-7
64	CBW GSL, Christie Bay W.	08-Aug	07:53	11.9	11.5	0-4
65	CBE GSL, Christie Bay E.	08-Aug	08:30	12.3	11.5	0-4
66	MCL GSL, McLeod Bay	08-Aug	09:05	11.3	11.5	0-7
67	GOR Gordon Lake	08-Aug	10:13	16.8	11.5	0-9
68	YK6 YKB location 6	09-Aug	08:38	15.4	16.0	0-9
69	YK5 YKB location 5	09-Aug	09:13	15.8	16.0	0-9
70	YK4 YKB location 4	09-Aug	09:50	16.0	16.0	0-5
71	YK3 YKB location 3	09-Aug	10:17	16.4	16.0	0-4
72	YK2 YKB location 2	09-Aug	10:35	16.5	16.0	0-4
73	YK1 YKB location 1	09-Aug	10:52	15.8	16.0	0-1.5
74	YK6 YKB location 6	17-Aug	08:15	12.6	13.5	0-8
75	YK5 YKB location 5	17-Aug	08:45	13.3	13.5	0-8
76	YK4 YKB location 4	17-Aug	09:25	13.4	13.5	0-8
77	YK3 YKB location 3	17-Aug	10:00	13.8	13.5	0-3
78	YK2 YKB location 2	17-Aug	10:25	14.5	13.5	0-4
79	YK1 YKB location 1	17-Aug	10:55	14.6	13.5	0-1.5

Appendix 2. Temperature vs depth profiles. "Loc" refers to the station location, see Appendix 1 for the key to these abbreviations.

		depth in metres																
Sta	Loc	0.0	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	13.0	14.0	15.0	20.0
1	YK1	8.9	8.9	8.9														
2	YK3	6.5	6.3	6.5	6.5	6.1	5.6	4.1	3.8	3.4	3.2	3.0	2.9	2.9				
4	ALX	12.7			12.2	11.9	10.9	9.8	8.3	7.9	6.9							
5	CHI	14.6	14.6	13.9	13.8	13.5	12.6	10.7	7.0	6.0								
6	DRY	12.1	12.0	11.3	11.2	11.0	10.2	9.6	9.5	9.1	8.4	7.9	7.2	6.5	6.0			
7	BAP	12.9	12.9	12.6	12.2	11.6	11.3	9.7	9.2	8.4	7.4	6.0	5.7					
8	PRO	7.3	7.1	7.0	7.0	6.9	6.8	6.8	6.7	6.6	6.6	6.4	6.3	5.4	5.1	5.0	4.9	4.8
9	W2	8.6			8.2		8.0		7.9			7.8						
10	W1W	9.6		9.4		9.2		9.2		9.2		9.1						
11	W1E	8.1		8.0		7.9		7.8		7.8		7.7						
12	W3	8.5	8.4	8.2	5.8	4.8	4.6	4.6	4.5	4.4	4.4	4.4						
13	W5	7.4	7.2	6.7	6.2	6.0	5.8	5.5	5.3	5.2	5.1	4.9						
14	W4	6.8	6.6	6.5	6.5	6.3	6.3	6.3	6.3	6.3	6.3	6.3						
15	YK6	13.1	12.9	12.5	8.7	7.0	6.6	5.9	5.5	5.3	5.1	4.8	4.6	4.6	4.5	4.5	4.5	4.4
16	YK5	14.2	14.1	13.7	13.6	13.4	10.7	9.4	8.5	7.2	6.9	6.6	6.2	5.8	5.5	5.4	5.2	4.6
17	YK3	17.4	17.2	16.4	16.1	15.5	13.8	11.1	9.4	8.8	8.5	8.3						
18	YK2	17.7	17.4	16.9	16.4	15.5	13.2	10.9	10.5	10.0	9.5	9.1						
19	YK1	17.8	17.3	16.9														
20	HCW	5.0	4.9	4.8	4.7	4.7	4.7	4.6	4.6	4.5	4.4	4.4					4.3	
21	HCE	6.1	5.9	5.7	5.4	5.2	5.1	5.0	4.9	4.8	4.7	4.6					4.5	
22	CBW	4.3	4.1	4.0	3.9	3.9	3.9	3.8	3.8	3.8	3.8	3.7					3.8	
23	CBE	4.2	3.9	3.8	3.7	3.7	3.5	3.5	3.5	3.5	3.5	3.5					3.4	3.4
24	MCL	4.2	4.0	3.9	3.9	3.8	3.9	3.8	3.8	3.7	3.7	3.7					3.7	3.6
25	GOR	13.1	13.0	12.9	12.8	12.7	12.6	12.5	11.3	10.9	10.4	8.5	7.5	7.0	6.7	6.4	6.2	5.3
26	YK6	10.1	10.1	10.1	10.0	10.0	10.0	10.0	9.9	9.8	9.5	9.1	8.4	8.1	7.5	7.4	7.2	6.4
27	YK5	11.6	11.5	11.2	10.8	10.4	10.3	10.0	9.8	9.2	8.9	8.8	8.8				8.5	7.6
28	YK4	14.6	14.2	13.5	13.1	12.3	11.7	11.2	10.7	10.5	10.1	9.4	9.0					
29	YK3	15.4	15.4	14.5	14.1	11.9	11.3	10.8	10.0	9.8	9.6	9.5					9.0	
30	YK2	15.2	15.1	14.6	14.1	13.7	12.7	11.2	10.2	9.7	9.5	9.2						
31	YK1	14.3	14.3	14.1														
32	PRO	16.0	15.9	15.9	15.9	15.5	14.6	13.4	11.8	9.8	8.8	7.8	7.4	7.3	7.1	7.0	6.9	6.1
33	BAP	17.0	17.1	17.1	17.1	17.1	16.5	15.0	10.1									
34	DRY	16.7	16.7	16.7	16.7	16.6	16.4	15.8	13.7	12.4	9.5	8.4	7.7	7.0	6.9	6.6	6.4	
35	CHI	17.9	17.9	17.8	17.7	17.7	17.3	15.0	10.2	8.3	7.0	6.5	5.9	5.4	5.1	5.0	4.9	
36	ALX	17.2	17.2	17.1	17.0	16.9	16.4	15.8	12.6	10.3	9.0	8.0	7.4	7.0	6.8	6.1	5.9	4.8
37	MAD	18.9	18.9	18.9	18.1	17.5	16.1	13.8	11.1	8.6	8.4							
38	YK4	11.7	11.6	11.6	11.5	11.3	11.0	10.8	10.3	9.2	9.0	8.7	8.4	8.1	7.9			
39	YK6	12.1	12.1	11.7	8.5	7.8	7.2	6.9	6.8	6.7	6.5	6.4	6.3	6.2	6.2	6.1	6.1	5.9
40	YK5	13.6	13.5	13.5	13.4	13.2	8.9	8.1	7.4	6.9	6.7	6.6	6.5	6.4	6.3	6.2	6.1	5.8
41	YK4	14.8	14.6	13.3	11.4	10.3	9.7	9.0	8.6	8.4	8.1	7.9						
42	YK3	15.4	15.2	13.9	12.4	10.6	9.3	8.7	8.5	8.2	7.7	7.6						
43	YK2	16.3	16.1	14.8	13.4	11.9	10.0	9.3	9.0	8.8	8.4	8.2						
44	YK1	16.1	15.4	14.3														
45	YK6	13.4	13.3	12.4	8.3	7.3	7.1	6.9	6.8	6.6	6.5	6.4	6.3	6.3	6.1	6.1	6.1	6.0
46	YK5	16.6	16.6	15.8	14.7	9.8	7.2	6.8	6.7	6.6	6.4	6.4	6.3	6.2	6.1			
47	YK4	16.7	15.8	10.1	8.9	8.1	7.7	7.5	7.2	7.1	7.0	6.9						
48	YK3	11.1	11.0	10.3	8.6	8.4	8.2	7.8	7.4	7.3	7.1	7.1						

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49  YK2 13.3 13.2 12.9 10.4  8.8  8.2  7.8  7.7  7.4  7.3  7.2
50  YK1 18.6 18.2 17.7
51  YK6 15.8 15.7 15.7 15.3 15.0 14.9 14.5 14.3 13.8 13.2 11.8 11.0 10.5 10.3 10.2  9.8  8.7
52  YK5 15.6 15.5 15.5 15.4 14.7 14.3 13.5 12.4 12.2 11.7 11.5 11.2 11.1 11.0 10.9 10.9  9.3
53  YK4 15.6 15.6 15.2 13.7 10.6  9.0  8.3  8.0  7.8  7.6  7.4
54  YK3 15.3 15.3 13.8 11.5  9.6  9.0  8.8  8.5  8.3  8.2  8.1
55  YK2 16.0 16.0 15.6 11.9 10.0  9.1  8.5  8.2  7.9  7.7  7.5
56  PRO 17.4 17.4 17.4 17.4 17.4 17.3 17.3 17.3 10.9  9.8  8.6  8.0  7.7  7.5  7.3  7.1  6.5
57  BAP 17.9 17.9 17.9 17.9 17.9 17.7 17.6 15.3 12.5 10.7  9.2  8.2  7.4  7.0  6.3  5.7  4.8
58  DRY 17.8 17.8 17.8 17.8 17.8 17.8 17.7 15.4 14.3 12.6 10.2  8.7  7.9  7.4  7.1  6.7  6.0
59  CHI 18.1 18.1 18.1 18.1 18.1 18.0 17.0 12.9  9.8  7.9  7.2  6.5  6.0  5.7  5.4  5.1
60  ALX 17.8 17.8 17.8 17.8 17.8 17.8 17.4 15.8 13.7 11.5  9.2  8.1  7.7  7.0  6.8  6.3  5.2
61  MAD 18.6 18.6 18.5 18.5 18.5 16.5 14.2 12.6 10.6  9.0
62  HCW 11.1 11.0 10.9 10.8 10.7 10.6 10.4 10.3 10.1  9.7  9.4  8.9  8.7  8.1  7.8  7.6  6.9
63  HCE 11.3 11.0 10.7 10.6 10.5 10.5 10.4 10.3 10.1 10.0  9.5  9.2  8.8  8.5  8.2  8.1  6.7
64  CBW 11.9 11.9 11.7 11.0 10.5  8.9  8.3  8.0  7.6  7.4  7.1  7.0  6.9  6.8  6.8  6.7  6.1
65  CBE 12.3 12.3 12.1 11.5  9.8  9.3  9.2  8.9  8.7  8.5  8.4  7.7  7.0  6.7  6.6  6.4  5.6
66  MCL 11.3 10.7 10.4 10.1  9.4  8.7  8.2  7.7  7.3  7.0  6.7  5.9  5.5  5.3  5.2  5.1  4.9
67  GOR 16.8 16.8 16.8 16.7 16.7 16.7 16.6 16.5 16.2 15.4 13.3 12.7 12.2 11.8 11.2 10.9  9.7
68  YK6 15.4 15.4 15.4 15.3 15.3 15.3 15.3 15.3 15.3 15.3 15.2 14.9 14.3 13.2 11.4 10.5  8.2
69  YK5 15.8 15.8 15.8 15.8 15.8 15.8 15.8 15.5 15.5 15.3 15.1 14.9 14.6 13.9 12.9 10.9  7.3
70  YK4 16.0 15.9 15.9 15.9 15.9 15.8 14.4 11.3 10.7  9.6  9.4  9.0  8.7
71  YK3 16.4 16.4 16.4 16.3 16.3 15.3 13.5 11.7 10.9  9.2
72  YK2 16.5 16.5 16.4 16.4 16.4 16.0 14.2 11.7 10.1  9.6  9.0
73  YK1 15.8 15.8 15.8
74  YK6 12.6 12.6 12.6 12.6 12.5 12.5 12.5 12.4 11.9 10.9 10.6  9.7  9.5  9.2  8.9  8.6  7.3
75  YK5 13.3 13.3 13.3 13.3 13.3 13.3 13.3 13.3 13.3 11.9  9.8  9.4  9.4
76  YK4 13.4 13.4 13.4 13.4 13.4 13.2 13.2 13.2 12.8 12.0 11.4
77  YK3 13.8 13.8 13.8 13.7 12.4 11.4 10.5  9.8  9.4  9.2  9.0
78  YK2 14.5 14.5 14.5 14.5 14.3 13.8 13.6 13.3  9.9  9.5  9.1
79  YK1 14.6 14.6 14.6
```

Appendix 3. In situ transparency data. "Air" values are in units of microEinsteins.$m^{-2}.s^{-1}$. Values for depths are percentages of the surface value and are corrected for the "immersion factor" (1.34) for the LI-192S sensor (see Lambda Instr. Co., Lincoln, Neb. for details). "Loc" refers to the station location, see Appendix 1 for the key to these abbreviations.

			Depths, metres																			
Sta	Loc	Air	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	13.0	14.0	15.0	16.0	17.0
1	YK1	940	50.6	26.8	14.9	8.9																		
2	YK3	1100	82.7	31.8	21.6	16.5	10.2	8.9	5.5	3.7		1.9												
3	YK5	1200	63.0	38.5		21.0		11.7		5.8		3.4												
9	W2	600		46.7		23.3		14.0		8.2		4.9												
10	W1W	700		50.0		22.0		13.0		7.0		4.2	2.6											
11	W1E	750		39.2		16.8		8.4		4.7		2.8	1.3											
12	W3	950	22.1	6.6	4.4	0.7																		
13	W5	1100	53.5	30.5	17.8	11.5	7.6	5.1		2.1														
14	W4	1150	67.0	42.6		20.7		13.4																
15	YK6	550	67.5	48.4	31.8	23.4	16.5	12.2	8.9	6.6	4.7	3.6	2.0	1.1	0.7	0.4	0.2							
16	YK5	800	56.0	41.1	28.0	20.1	10.7		8.2	5.8	4.6	3.3	1.9	1.2	0.7	0.4	0.3							
17	YK3	840	70.0	45.8	31.7	22.5	15.5	10.8	8.0	5.8	4.2	2.9	1.6	0.9	0.5	0.3	0.2							
18	YK2	910	70.0	47.7	32.3	21.5	14.9	10.6	7.8	5.6	4.2	3.0	1.7	0.9	0.5	0.3	0.2							
19	YK1	1075	59.9	42.3	30.6	21.5	15.0																	
20	HCW	380		46.1		18.4		11.1		5.9		3.6	2.3	1.5	1.0	0.6	0.4							
21	HCE	215		65.1		48.8		31.3		18.9		11.4	7.8	5.5	4.0	3.3	2.5							
22	CBW	780		50.3		26.9		18.8		15.1		11.3	8.6	5.7	4.7	3.5	2.8							
23	CBE	265		52.3		34.9		26.4		21.1		16.4	12.4	9.8	7.9	6.4	5.2							
24	MCL	215		60.6		49.5		41.0		34.5		28.7	24.7	21.5	18.6	16.3	14.0							
25	GOR	180		60.7		45.1		36.6		30.3		25.7	22.2	19.3										
26	YK6	405	71.9	50.1	36.3	26.3	18.3	13.7	10.4	7.8	5.7	4.3	2.5	1.5	0.9	0.6	0.3							
27	YK5	148	61.0	45.4	33.1	23.6	17.8	13.5	10.0	7.4	5.5	4.3	2.6	1.5	0.9	0.6	0.4							
28	YK4	122	64.3	48.2	35.0	27.8	20.1	16.3	12.0	8.8	6.9	5.1	2.9	1.7	0.9									
29	YK3	213	67.0	49.3	36.2	27.6	20.7	15.9	12.2	9.2	7.0	5.5	3.3	2.0	1.2	0.7	0.4							
30	YK2	280	67.5	48.8	36.3	27.0	20.5	16.0	12.4	9.5	7.4	5.6	3.3	2.0	1.3	0.9	0.6							
31	YK1	500	68.6	50.4	36.4	29.4	22.4																	
32	PRO	255	68.6	50.5	39.0	31.3	25.3	20.9	16.5	13.5	10.7	9.1	5.8	3.9	2.7	1.9	1.3							
33	BAP	320	59.1	43.8	36.8	30.2	25.4	21.4	18.4	15.3	12.9	10.9	8.1	5.7	3.2									
34	DRY	390	66.4	50.3	41.3	34.8	30.5	25.1	21.2	17.6	15.6	13.6	10.4	7.7	5.7	4.3	3.2							
35	CHI	570	61.4	46.7	35.6	30.7	23.3	18.9	16.9	14.2	11.8	9.6	6.8	4.5	3.2	2.1	1.6							
36	ALX	580	82.1	65.2	48.3	38.6	31.4	26.6	22.9	20.5	18.1	14.2	10.1	5.9										
37	MAD	690	59.9	34.5	16.6	11.2	8.1	6.7	5.0	3.6	2.5	1.7	0.8											
38	YK4	165	65.3	46.2	33.1	23.9	17.4	12.7	9.1	6.6	4.8	3.6	1.9	1.1	0.6	0.3	0.2							

39	YK6	370	64.3	45.4	32.2	22.7	16.6	12.5	9.1	6.8	4.8	3.5	1.9	1.1	0.6	0.3	0.2								
40	YK5	670	59.6	47.0	33.4	25.1	19.0	14.6	10.9	8.4	6.5	4.6	2.4	1.2	0.7	0.4	0.2								
41	YK4	750	67.2	46.7	31.7	24.3	17.5	12.5	9.1	6.5	4.8	3.4	1.8	0.9	0.5	0.2	0.1								
42	YK3	940	67.0	49.1	35.7	26.8	18.6	14.0	10.3	7.5	5.5	3.9	2.0	1.0	0.5	0.3	0.1								
43	YK2	1050	65.3	48.7	36.0	25.3	19.3	14.4	10.7	7.9	5.9	4.3	2.2	1.1	0.6	0.3	0.1								
44	YK1	690	67.0	51.7	38.6	26.4																			
45	YK6	850	59.3	37.9		18.1		8.9		4.9		2.6	1.5	0.8	0.4	0.2	0.1								
46	YK5	940	67.0	46.2		26.1		14.3		7.9		4.5	2.4	1.4	0.7	0.4	0.2								
47	YK4	1625	71.1	51.7		24.6		11.6		5.8		2.8	1.4	0.7	0.3	0.2	0.1								
48	YK3	1100	71.3	49.6		23.5		11.2		5.6		2.9	1.4	0.7	0.4	0.2	0.1								
49	YK2	1200	74.7	54.8		28.0		14.0		7.5		4.0	2.0	1.0	0.5	0.3	0.1								
50	YK1	1325	71.3	48.6	34.9	29.1																			
51	YK6	430	70.0	50.5	37.4	28.0	20.5	15.6	11.7	9.1	7.2	5.5	3.3	2.0	1.3	0.8	0.5								
52	YK5	540	70.0	49.3	33.7	24.1	17.9	13.2	9.9	7.4	5.7	4.1	2.4	1.4	0.8	0.5	0.3								
53	YK4	580	62.8	45.9	33.8	25.3	18.8	14.2	10.4	7.7	5.6	3.9	1.9	1.0	0.5	0.3	0.2								
54	YK3	450	67.8	46.7	34.2	25.8	18.7	13.4	9.6	6.8	4.8	3.5	1.8	1.0	0.5										
55	YK2	475	72.2	51.6	36.8	28.0	20.9	16.5	12.7	9.1	6.6	4.9	2.8	1.5	0.8	0.5	0.3								
56	PRO	245	54.9	39.4	27.4	20.6	15.4	12.0	9.1	7.4	6.0	5.0	3.7	2.3	1.7	1.1	0.8								
57	BAP	190	67.8	50.8	39.1	33.9	28.7	22.8	20.3	17.7	14.0	11.8	8.8	6.5	4.6	3.3	2.4								
58	DRY	230	73.0	53.6	42.6	37.1	31.7	26.8	23.1	20.1	17.7	15.2	11.9	8.8	6.4	4.7	3.5								
59	CHI	710	67.0	49.3	33.5	29.6	23.7	19.7	15.2	13.6	11.0	9.5	6.3	4.5	3.1	2.2	1.4								
60	ALX	800	83.1	61.3	48.1	35.0	28.9	23.6	19.3	18.4	14.7	12.8	9.3	7.0	5.1	3.8	2.6								
61	MAD	960	58.3	34.3	20.4	13.0	8.9	6.0	4.2	2.9	1.9	1.3	0.4	0.1	0.1										
62	HCW	151	43.6	31.5	23.2	18.5	14.8	12.5		8.3		6.0	3.9	2.8	1.7	1.2	0.8								
63	HCE	450		43.6		28.3		18.4		12.8		8.6	5.8	4.0	2.9	2.3	1.7								
64	CBW	500	61.6	46.2	32.2	26.3	23.2	20.2	16.5	14.0	10.6	8.7	6.2	3.9	2.9	2.3	1.7	1.3	0.9	0.7	0.6	0.4			
65	CBE	650	75.4	56.0	42.0	32.3	26.9	20.0	18.7	15.7	11.8	10.1	7.1	5.2	3.4	2.6	1.8	1.4	1.0	0.8	0.6	0.5			
66	MCL	800	73.5	64.8	54.3	49.0	43.8	37.6	35.9	31.5	25.4	22.8	17.5	15.1	12.3	10.0	8.2	6.8	5.8	4.8	4.1	3.4	2.9	2.5	
67	GOR	1050	81.3	69.3	56.0	46.7	42.0	38.0	33.3	28.7	27.3	24.0	19.3	15.3	12.5	10.0	8.0	6.7	5.2	4.1	3.3	2.6	2.0	1.6	
68	YK6	850	62.6	49.4	32.9	23.9	18.1	12.7	9.7	6.9	5.6	4.4	2.6	1.8	1.1	0.7	0.5	0.3	0.2	0.1					
69	YK5	850	74.1	44.5	35.4	26.4	18.9	13.2	10.0	7.6	6.1	4.8	2.8	1.9	1.1	0.7	0.4	0.3	0.2	0.1					
70	YK4	520	72.7	49.8	33.7	25.6	19.4	13.5	9.4	6.7		4.0	2.6	1.5	0.8	0.5	0.3								
71	YK3	870	66.0	51.5	33.8	24.1	18.5	14.8	10.5	7.6	5.8	4.3	2.5	1.5	0.8	0.4	0.2								
72	YK2	1150	57.8	45.0	32.9	25.0	18.9	13.4	11.0	7.8	6.1	4.6	2.7	1.6	0.9	0.4	0.2								
73	YK1	1300	58.2	48.5	32.8																				
75	YK5	195	71.8	50.3	36.6	25.8	20.1	14.7	10.8	8.3	6.4	4.8													
76	YK4	1075	52.1	39.7	30.0	19.5	13.7	9.0	6.9	4.9	3.5	2.6	1.2	0.8	0.4	0.2	0.1								
77	YK3	460	60.9	42.6	30.1	22.2	16.7	13.1	9.4	7.6	5.8	4.1	2.3	1.2	0.6	0.3	0.1								
78	YK2	630	65.6	50.0	33.3	24.4	19.8	14.4	11.3	8.7	6.9	5.0	3.0	1.7	1.0	0.5	0.3								
79	YK1	350	68.0	48.0	35.6	26.4																			

Appendix 4. Transparency related variables. The units of Secchi depth are metres. Extinction coefficients are calculated from the data in Appendix 3 and are in units of $metre^{-1}$. Mean light values were calculated with the program in Fee (1984) from the mixing depth (Appendix 1) and transparency (Appendix 3) data assuming a cloudless distribution of light during the day and have units of $milliEinsteins.m^{2}.min^{-1}$. Euphotic zone depths are the depths (in metres) at which 0.5% of surface light occurs and were calculated from the data in Appendix 3. "Loc" refers to the station location, see Appendix 1 for the key to these abbreviations.

Sta	Loc	Secchi color	Secchi depth	Absorb. @543nm	Ext. Coeff.	Mean Light	Euphotic zone
1	YK1	Brown	1.2	NA	1.16	25.8	4.8
2	YK3	Brown/Green	2.0	NA	0.80	19.6	7.0
3	YK5	Brown/Green	2.1	NA	0.64	17.2	8.6
4	ALX	Brown/Green	6.5	0.014	NA	33.1	NA
5	CHI	Blue/Green	5.3	0.019	NA	24.2	NA
6	DRY	Blue/Green	7.0	0.013	NA	29.7	NA
7	BAP	Blue/Green	7.6	0.017	NA	22.4	NA
8	PRO	Milky Green	5.0	0.027	NA	12.9	NA
9	W2	Green	4.0	0.031	0.56	5.4	9.4
10	W1W	Green	3.8	0.035	0.58	5.3	9.4
11	W1E	Brown	2.5	0.065	0.66	4.3	7.2
12	W3	Brown	0.5	0.485	2.12	10.3	2.1
13	W5	Brown	1.7	0.104	0.91	3.3	5.6
14	W4	Green	2.8	0.058	0.64	5.0	10.6
15	YK6	Green	2.7	0.045	0.59	31.3	8.6
16	YK5	Green	2.6	0.052	0.55	20.0	8.6
17	YK3	Green	2.1	0.067	0.63	22.8	8.0
18	YK2	Brown/Green	1.9	0.075	0.63	25.1	8.0
19	YK1	Green	2.1	0.068	0.69	34.6	7.2
20	HCW	Brown/Green	3.7	0.031	0.51	4.9	9.4
21	HCE	Blue	6.3	0.016	0.38	9.0	15.8
22	CBW	Blue	12.7	0.007	0.31	7.2	17.7
23	CBE	Blue	12.0	0.011	0.25	9.2	21.3
24	MCL	Blue	11.5	0.007	0.16	14.9	31.9
25	GOR	Blue	9.8	0.010	0.19	22.7	33.1
26	YK6	Brown/Green	3.0	0.040	0.56	7.5	9.4
27	YK5	Brown/Green	2.8	0.052	0.54	7.0	9.4
28	YK4	Brown/Green	2.5	0.052	0.56	27.9	8.9
29	YK3	Brown/Green	2.4	0.054	0.52	28.5	9.6
30	YK2	Brown/Green	2.6	0.049	0.51	24.1	10.4
31	YK1	Brown/Green	2.5	0.045	0.56	40.2	9.5
32	PRO	Green	4.3	0.030	0.41	NA	12.5
33	BAP	Green	8.0	0.008	0.36	NA	11.2
34	DRY	Blue/Green	8.0	0.008	0.31	NA	16.3
35	CHI	Green/Brown	6.2	0.018	0.38	NA	14.3
36	ALX	Blue/Green	7.5	0.005	0.38	NA	14.8
37	MAD	Brown	2.4	0.069	0.74	NA	6.6
38	YK4	Green/Brown	1.0	0.075	0.63	NA	8.3
39	YK6	Green/Brown	2.1	0.064	0.62	NA	8.3
40	YK5	Green/Brown	2.9	0.051	0.60	NA	8.6
41	YK4	Green/Brown	2.8	0.056	0.66	NA	8.0

42	YK3	Green/Brown	2.9	0.054	0.65	NA	8.0
43	YK2	Green/Brown	2.9	0.053	0.64	NA	8.3
44	YK1	Green/Brown	NA	0.051	0.62	NA	7.2
45	YK6	Green/Brown	2.1	0.057	0.63	23.0	7.7
46	YK5	Green/Brown	3.1	0.038	0.60	28.2	8.6
47	YK4	Green/Brown	2.4	0.050	0.72	38.5	7.4
48	YK3	Green/Brown	2.1	0.066	0.70	27.8	7.6
49	YK2	Green/Brown	2.4	0.053	0.66	30.8	8.0
50	YK1	Green/Brown	NA	0.038	0.61	38.3	13.2
51	YK6	Green	3.1	0.035	0.52	25.4	10.0
52	YK5	Green/Brown	2.6	0.042	0.57	29.5	9.0
53	YK4	Green/Brown	3	0.065	0.64	27.6	8.0
54	YK3	Green/Brown	2.8	0.065	0.65	28.3	8.0
55	YK2	Green/Brown	2.8	0.058	0.59	30.5	9.0
56	PRO	Gray/Blue	5.5	0.028	0.39	12.5	11.5
57	BAP	Blue	6.5	0.015	0.34	21.6	14.9
58	DRY	Blue	7.8	0.010	0.30	22.9	16.6
59	CHI	Green	6.1	0.014	0.38	21.5	12.3
60	ALX	Blue	7.5	0.012	0.33	23.9	14.3
61	MAD	Brown	2.1	0.078	0.92	13.5	6.1
62	HCW	Green	4.5	0.026	0.40	9.8	9.8
63	HCE	Blue/Green	6	0.015	0.36	8.1	9.4
64	CBW	Blue/Green	6.8	0.018	0.34	22.4	14.4
65	CBE	Blue/Green	6.5	0.014	0.35	26.0	15.0
66	MCL	Blue	9	0.010	0.21	21.1	27.8
67	GOR	Blue	9.6	0.010	0.23	21.8	22.2
68	YK6	Green	3.8	0.025	0.48	8.2	10.0
69	YK5	Green/Brown	3	0.040	0.50	8.7	9.6
70	YK4	Green/Brown	2.6	0.047	0.57	19.5	9.0
71	YK3	Green/Brown	2.7	0.042	0.59	22.8	8.7
72	YK2	Green/Brown	2.7	0.040	0.57	21.5	8.7
73	YK1	Green/Brown	NA	0.045	0.57	38.8	6.8
74	YK6	Green/Brown	2.6	0.054	NA	11.4	NA
75	YK5	Green/Brown	2.3	0.057	0.48	11.2	8.9
76	YK4	Green/Brown	2.1	0.067	0.65	9.7	7.7
77	YK3	Green/Brown	2.5	0.048	0.63	24.0	8.3
78	YK2	Green/Brown	2.6	0.046	0.61	18.5	9.0
79	YK1	Green/Brown	NA	0.046	0.63	39.8	8.6

Appendix 5. Chemical data. "Loc" refers to the station location, see Appendix 1 for the key to these abbreviations.

		uMoles.L^{-1}														mg.L^{-1}		uS.cm^{-1}	
		Nitrogen			Phosphrus		Carbon											cond	
Sta	Loc	NO_3	Susp	TD	Susp	TD	Susp	DIC	DOC	Alk	Cl	SO_4	Na	K	Ca	Mg	Si	TSS	@25C	pH
1	YK1	2.1	4.4	24	0.49	0.48	33	450	600	446	113	100	133	24	207	109	0.31	10	90	7.96
2	YK3	2.1	3.6	21	0.22	0.29	25	490	720	570	107	98	134	23	220	123	0.39	4	80	7.68
3	YK5	2.1	2.3	18	0.17	0.19	19	920	610	1022	169	164	209	23	456	185	0.82	1	150	7.54
4	ALX	0.4	1.9	38	0.11	0.29	20	750	800	996	90	60	151	59	278	218	0.20	1	120	7.94
5	CHI	0.0	2.4	37	0.14	0.23	23	780	1230	951	96	56	166	55	256	203	0.10	1	110	7.78
6	DRY	0.0	1.6	18	0.08	0.19	17	730	740	881	141	75	166	52	267	185	0.61	1	120	7.84
7	BAP	0.0	2.0	30	0.11	0.19	17	800	870	972	124	71	175	59	278	185	0.39	1	120	8.00
8	PRO	0.0	2.9	21	0.11	0.19	22	290	580	278	48	37	71	22	105	65	0.15	1	50	7.44
9	W2	4.2	1.5	22	0.13	0.32	16	1040	1450	1570	240	239	323	26	646	254	1.25	NA	220	8.13
10	W1W	1.5	3.1	19	0.13	0.32	28	1100	970	1570	169	167	313	23	679	261	1.10	NA	210	8.17
11	W1E	3.8	1.4	20	0.14	0.32	12	1040	600	1620	268	224	320	23	690	254	1.33	NA	220	8.23
12	W3	4.0	3.7	21	0.61	0.48	25	1160	600	1660	212	193	351	25	735	279	1.47	NA	230	8.28
13	W5	2.8	1.9	19	0.21	0.36	18	980	460	1515	212	193	285	22	634	239	1.33	NA	200	8.28
14	W4	2.5	2.2	17	0.14	0.32	20	960	440	1470	183	203	283	22	601	239	1.14	NA	200	8.24
15	YK6	0.4	4.3	16	0.17	0.23	33	900	510	1430	169	172	271	25	557	225	1.13	2	190	8.22
16	YK5	0.1	3.4	17	0.14	0.29	28	780	500	1225	155	167	239	26	468	196	0.86	2	170	8.21
17	YK3	0.7	5.3	22	0.30	0.45	32	550	480	700	135	110	158	26	278	134	0.38	3	100	8.01
18	YK2	0.7	3.9	21	0.21	0.39	25	480	550	635	124	102	144	25	245	123	0.32	NA	100	7.96
19	YK1	1.2	3.9	22	0.16	0.39	30	470	590	625	135	104	146	25	245	120	0.31	3	100	7.89
20	HCW	5.8	0.8	25	0.09	0.36	10	1140	730	1540	226	203	295	25	612	243	1.40	1	200	8.34
21	HCE	5.1	1.6	24	0.09	0.23	13	900	760	1410	197	182	274	24	557	229	1.30	1	190	8.31
22	CBW	6.6	0.9	21	0.10	0.23	9	NA	790	1355	197	177	270	23	545	221	1.33	0	180	8.28
23	CBE	6.4	1.4	24	0.08	0.19	12	860	640	1365	197	193	277	24	545	214	1.33	1	180	8.28
24	MCL	6.3	1.5	21	0.07	0.26	12	180	220	220	34	22	43	10	66	40	0.21	0	30	8.00
25	GOR	0.0	2.4	19	0.11	0.19	18	480	350	635	56	75	78	29	219	87	0.10	0	80	7.80
26	YK6	3.3	4.0	20	0.18	0.23	28	900	1280	1530	197	193	301	29	657	258	1.26	2	200	8.10
27	YK5	2.2	3.4	19	0.19	0.19	22	960	1250	1475	212	193	288	27	657	243	1.21	2	190	8.18
28	YK4	1.4	3.7	19	0.19	0.26	25	880	550	1080	147	148	219	26	479	189	0.75	3	150	8.15
29	YK3	1.4	3.5	21	0.20	0.26	22	630	470	800	124	98	171	25	367	156	0.50	2	110	7.97
30	YK2	1.9	4.4	26	0.22	0.29	34	700	490	900	124	127	187	26	345	160	0.59	3	130	7.93
31	YK1	2.0	4.0	21	0.23	0.32	17	770	520	960	152	137	203	26	378	160	0.63	4	140	7.88
32	PRO	0.0	2.5	19	0.12	0.19	19	260	460	322	65	39	75	23	108	65	0.14	NA	50	7.93
33	BAP	0.0	2.1	23	0.08	0.19	18	800	740	990	130	69	179	66	301	196	0.36	NA	120	7.86
34	DRY	0.0	1.8	20	0.07	0.19	16	700	540	900	158	77	173	60	278	192	0.64	NA	120	7.92
35	CHI	0.0	3.1	35	0.12	0.19	28	810	1040	1000	96	55	171	60	256	214	0.10	NA	110	8.00
36	ALX	0.0	2.6	31	0.14	0.19	19	820	900	1005	87	61	149	64	267	218	0.19	NA	120	7.98
37	MAD	0.0	13.8	41	0.30	0.32	89	1180	1280	1590	1058	78	799	106	512	406	1.19	NA	280	8.28
38	YK4	0.0	3.4	24	0.21	0.26	27	760	460	1080	147	154	214	26	422	167	0.86	3	160	8.14
39	YK6	3.4	3.0	34	0.15	0.36	23	1020	690	1500	197	198	283	26	598	221	1.25	1	200	8.20
40	YK5	2.3	3.4	24	0.13	0.39	28	740	630	1150	197	167	225	27	453	172	0.90	2	160	8.10
41	YK4	1.9	3.8	31	0.22	0.58	26	890	700	1100	152	152	220	26	444	172	0.86	2	160	8.08
42	YK3	2.0	NA	21	0.17	0.42	NA	870	650	1035	147	144	212	26	413	160	0.78	NA	150	8.10
43	YK2	2.6	3.6	46	0.15	0.42	25	730	660	900	147	135	193	28	364	144	0.65	2	130	8.00
44	YK1	3.5	3.7	24	0.14	0.29	25	840	720	1000	212	161	221	28	440	161	0.75	1	150	8.06
45	YK6	1.9	3.1	19	0.12	0.23	19	1140	750	1440	212	198	290	25	600	216	1.26	2	210	7.96
46	YK5	2.1	2.4	22	0.11	0.23	17	900	640	1080	186	164	215	26	433	164	0.80	1	150	7.86

47	YK4	2.9	2.7	19	0.16	0.23	20	840	740	1140	164	167	225	26	498	176	0.90	NA	160	7.90
48	YK3	3.6	2.9	23	0.21	0.26	23	940	730	1350	197	177	267	26	569	203	1.12	3	180	7.90
49	YK2	3.1	2.4	36	0.17	0.32	17	760	680	1045	212	161	244	28	509	182	0.98	2	170	7.94
50	YK1	1.5	2.9	24	0.17	0.26	27	680	550	715	338	125	186	26	360	139	0.57	1	130	7.30
51	YK6	1.2	2.7	19	0.14	0.19	19	1290	620	1510	254	193	284	25	620	222	1.15	2	210	8.14
52	YK5	0.0	3.4	19	0.20	0.16	20	1290	580	1460	212	182	279	28	584	213	1.09	2	200	8.14
53	YK4	1.6	2.8	25	0.20	0.26	18	1280	620	1470	226	182	290	26	578	207	1.15	2	200	7.96
54	YK3	3.5	3.4	23	0.20	0.23	20	1310	630	1460	324	213	277	27	589	213	1.18	2	200	7.92
55	YK2	2.9	4.0	26	0.16	0.23	22	1310	670	1410	212	193	277	29	562	206	1.15	2	190	7.90
56	PRO	0.0	2.2	19	0.14	0.19	20	280	480	304	59	41	73	22	113	67	0.13	NA	50	7.26
57	BAP	0.0	1.9	23	0.11	0.16	19	850	770	960	130	79	179	60	284	172	0.38	NA	120	7.94
58	DRY	0.0	1.6	21	0.09	0.23	16	810	NA	900	175	90	166	51	287	172	0.64	NA	120	7.90
59	CHI	0.0	2.6	37	0.10	0.23	26	800	1100	1020	90	62	168	57	269	191	0.10	NA	120	8.06
60	ALX	0.0	1.9	27	0.08	0.16	21	820	900	1070	102	79	146	59	280	197	0.19	NA	120	8.10
61	MAD	0.1	8.4	41	0.37	0.36	64	1260	1480	1600	367	697	769	104	509	363	1.00	3	290	8.32
62	HCW	4.1	2.4	25	0.17	0.26	19	1220	800	1490	381	239	279	23	589	216	1.44	1	200	8.22
63	HCE	4.8	2.3	20	0.09	0.13	16	1020	780	1350	56	255	246	21	540	204	1.39	1	180	8.26
64	CBW	3.6	2.4	24	0.10	0.16	20	1020	710	1370	324	224	248	21	518	190	1.37	NA	180	8.32
65	CBE	3.3	2.6	20	0.12	0.16	25	1080	820	1370	212	198	254	22	580	203	1.46	1	190	8.30
66	MCL	5.5	0.9	21	0.05	0.16	9	190	240	156	45	24	45	11	82	43	0.22	NA	30	7.80
67	GOR	0.0	1.3	20	0.06	0.39	17	530	440	650	48	79	79	27	240	90	0.11	NA	80	7.94
68	YK6	1.0	10.5	18	0.14	0.19	82	1300	690	1530	226	198	290	23	600	212	1.27	1	210	8.34
69	YK5	0.9	2.6	25	0.23	0.32	24	1240	650	1340	226	198	291	26	618	221	1.26	2	210	8.40
70	YK4	1.1	2.6	20	0.17	0.26	20	1120	650	1280	212	193	268	25	571	210	1.15	2	190	8.38
71	YK3	1.4	3.1	20	0.17	0.39	19	860	620	1160	183	172	223	25	453	172	0.82	NA	160	8.34
72	YK2	1.9	2.6	24	0.19	0.23	21	930	580	760	226	172	223	24	444	169	0.82	1	160	8.30
73	YK1	1.9	2.6	21	0.20	0.23	20	940	610	1120	212	172	245	26	480	185	0.80	2	170	8.34
74	YK6	1.9	2.2	20	0.19	0.23	17	1240	880	1530	226	203	292	25	637	224	1.21	2	210	8.40
75	YK5	2.1	2.1	21	0.25	0.26	19	1180	840	1510	226	229	276	24	611	218	1.15	2	200	8.38
76	YK4	2.9	2.2	25	0.16	0.29	17	920	810	1260	212	177	247	25	504	187	0.96	3	170	8.28
77	YK3	2.9	2.3	23	0.17	0.26	21	1030	830	1150	181	167	226	25	504	184	0.85	2	160	8.24
78	YK2	0.6	2.7	24	0.18	0.26	23	890	800	1000	175	156	198	25	400	154	0.71	2	140	8.18
79	YK1	2.4	2.6	20	0.21	0.26	23	1010	730	1130	353	187	223	25	462	175	0.81	2	160	8.20

Appendix 6. Phytoplankton and protozoan biomasses and phytoplankton identifications. A short table of abbreviations precedes the tabulated data. Percentages are the percent that a Group makes up of the total phytoplankton biomass in the sample. "Sum" is the percent that the named dominant groups make up of the total phytoplankton biomass in the sample. Dominant taxa are listed in order of abundance from left to right and top to bottom. Those taxa of equal abundance are separated by the symbol '~' instead of commas. "Loc" refers to the station location, see Appendix 1 for the key to these abbreviations.

Taxon codes		Group codes	
A.	= Asterionella	CHL	= chlorophyta
Ch.	= Chrysochromulina	CHR	= chrysophyceae
Cr.	= Cryptomonas	CRY	= cryptophyceae
D.	= Dinobryon	DIA	= diatomeae
D.b.	= D. bavaricum	PER	= peridineae
D.s.	= D. sociale	CYA	= cyanophyceae
Dm.	= Desmarella		
K.	= Kephyrion		
M.	= Melosira		
O.	= Oscillatoria		
P.	= Peridinium		
R.	= Rhodomonas		
R.l.	= R. lacustris		
R.l.m.	= R.l. minuta		
S.	= Synedra		

		$mg.m^{-3}$		Dominant		
Sta	Loc	Phyto	Proto	Group	%	Taxa
9	W2	411	33	DIA	78	M. islandica,
				CHR	9	Ochromonas spp.,
				CRY	7	Chrysococcus spp.,
				sum	94	R.l.m.
10	W1W	394	81	DIA	55	M. islandica,
				CHR	20	S. nana,
				CHL	9	Phacotus cf. lenticularis,
				sum	84	Koliella longiseta, Dm. moniliformis
11	W1E	288	51	DIA	58	M. islandica
				CHR	16	D. moniliformis
				CRY	14	Nitzschia acicularis
				sum	88	R.l., R.l.m.
12	W3	214	23	CRY	54	R.l., R.l.m., M. islandica
				DIA	23	Amphidium sp. ~ Gymnodinium sp.
				PER	17	abundant detritus
				sum	94	

13	W5	893	86	DIA	42	M. islandica, R.l.,
				CRY	24	Ochromonas spp,
				CHR	18	Chrysococcus sp ~
				sum	84	K. entzii ~ Ch. parva
14	W4	336	44	PER	42	P. aciculiferum,
				DIA	33	M. islandica,
				CRY	18	Cr. erosa,
				sum	93	R.l.
15	YK6	1346	151	CHR	66	Uroglena sp., Ch. parva,
				DIA	22	D.b. ~ D.s. stipitatum,
				CRY	8	D. divergens, M. islandica
				sum	96	R.l.
20	HCW	105	86	CRY	68	R.l., R.l.m., Cr. reflexa,
				CHR	12	Ch. parva, M. islandica,
				DIA	11	
				sum	91	
21	HCE	325	52	CRY	51	Cr. ovata, Cr. rostratiformis,
				CHR	31	Cr. marssoni, Ch. parva,
				PER	16	Pseudpedinella sp.,
				sum	98	Chrysococcus sp.
22	CBW	162	11	CRY	53	yeast (112 $mg.m^{-3}$),
				CHR	38	R.l.m., Ochromonas sp., Ch. parva,
				PER	9	Mallomonas spp., Glenodinium spp. ~
				sum	100	Gymnodinium sp.
23	CBE	266	110	CRY	43	R.l.m., Cr. marssoni, Ochromonas sp.,
				CHR	27	Chrysococcus spp., Ch. parva
				PER	16	Glenodinium sp.
				sum	86	
24	MCL	164	30	CHR	57	Ch. parva,
				CRY	25	Chrysococcus spp.,
				PER	14	K. entzii,
				sum	96	R.l., R.l.m.
25	GOR	317	34	CHR	79	Ochromonas spp.,
				CRY	9	D.b., D.s. stipitatum,
				PER	5	R.l.m.,
				sum	93	Gymnodinium spp.
26	YK6	838	19	CHR	71	Uroglena sp.,
				CRY	13	D. bavaricum,
				DIA	9	R.l.,
				sum	93	M. islandica
32	PRO	597	67	CHR	85	D. divergens, D.b., D.b. Vanhoeffenii,
				CRY	7	Uroglena sp., R.l.m., Gymnodinium sp.,
				PER	7	
				sum	99	

33	BAP	468	25	CHR	81	D.s. v. stipitatum, D.b., D. korschikovi,
				PER	7	Pseudokephyrion sp. ~ K. sp.,
				CHL	4	Gymnodinium uberrimum, K. ovalis,
				sum	92	Fragillaria sp.
34	DRY	444	281	CHR	62	D.s. v. stipitatum, Uroglena sp.,
				CYA	12	Ochromonas spp., C. parva, Aphanothece sp. ~
				CHL	10	Cyanodictyon sp., Monoraphidium sp. ~
				sum	84	Ankistrodesmus sp. ~ Elakatothrix sp.
35	CHI	525	20	CHR	52	D.b., D.s. v. americanum, O. limnetica,
				DIA	18	O. redekia, S. acus v. angustissima,
				CYA	15	S. acus v. radians
				sum	85	
36	ALX	725	34	CHR	48	D.s. v. stipitatum, C. parva, Ochromonas spp.,
				PER	25	D.b., P. aciculiferum, P. willei,
				DIA	12	Gymnodinium spp.
				sum	85	
37	MAD	2609	114	DIA	31	S. acus, S. spp. ~ Cyclotella spp.,
				CHR	22	Ochromonas spp. ~ Spiniferomonas spp.,
				CHL	17	Fragillaria sp.
				sum	92	Gloeobotrys limneticus, Chlamydomonas spp. ~
				sum	70	Monoraphidium spp.
39	YK6	549	0	CRY	56	R.l., R.l.m.,
				CHR	21	D.b., Pseudopedinella sp.,
				DIA	15	M. islandica
				sum	92	
45	YK6	571	98	CHR	65	Uroglena sp., Ch. parva,
				CRY	24	D.s. v. stipitatum,
				DIA	5	R.l., R.l.m.
				sum	94	
51	YK6	409	75	CHR	69	Synura spp., Ochromonas spp., Mallomonas spp.,
				CRY	15	D.s. v. stipitatum, R.l.m., R.l.,
				DIA	9	S. acus ~ A. formosa
				sum	93	
56	PRO	326	34	CHR	43	D.b., Ochromonas ~ Pseudopedinella spp.,
				CRY	38	C. parva ~ Chrysococcus sp., Cr. obovata,
				PER	17	R.l.m., Gymnodinium spp.
				sum	98	
57	BAP	956	17	CHR	87	D. divergens, Ochromonas spp.,
				CRY	5	Pseudopedinella sp., Chrysococcus spp.,
				CHL	4	K. ovalis, R.l.m.,
				sum	96	Tetraedron minimum, Oocystis sp.

58	DRY	241	38	CHR	74	Uroglena sp., Ochromonas spp., D.b.,
				CRY	14	Gloeobotrys limneticus, C. parva,
				PER	6	R.l. v. minuta, Gymnodinium uberrimum
				sum	94	
59	CHI	287	73	CHR	39	D.s. v. americanum, Ochromonas spp.,
				CYA	33	K. sp. ~ Pseudokephyrion spp.,
				CHL	9	Lyngbya limnetica, Aphanizomenon flos-aquae,
				sum	81	Botryococcus protuberans
60	ALX	434	31	CHR	50	D. divergens, D.b., Pseudokephyrion sp. ~
				CYA	17	K. sp., Ochromonas spp.,
				PER	10	Gloeobotrys limneticus,
				sum	77	Aphanizomenon gracile, Gymnodinium mirable
61	MAD	2215	38	CYA	65	Lyngbya birgei,
				DIA	20	Aphanizomenon flos-aquae ~ O. sp.,
				CHR	9	S. acus, Ochromonas spp. ~
				sum	94	G. limneticus, D.s. stipitatum
62	HCW	676	105	CHR	81	D.s., D.b., D.b. Vanhoeffenii,
				CRY	14	R.l., R.l.m.
				DIA	3	S. ulna
				sum	98	
63	HCE	658	65	CHR	81	D.b. Vanhoeffenii, D.s.,
				CRY	14	Cr. ovata, R.l.m.
				DIA	3	S. acus v. radians
				sum	98	
64	CBW	414	43	CHR	53	Ch. parva, Pseudopedinella sp.,
				CRY	31	D. cylindricum, D.b.,
				DIA	9	Cr. reflexa, Cr. rostratiformis,
				sum	93	S. acus v. radians
65	CBE	741	105	CHR	70	D.s., D.b.,
				CRY	20	Ochromonas sp., Cr. reflexa,
				PER	4	Glenodinium sp.
				sum	94	
66	MCL	105	17	CHR	40	Ochromonas spp.,
				PER	25	Ch. parva,
				CRY	23	Gymnodinium spp.,
				sum	88	R.l.
67	GOR	373	18	CHR	48	D.s. ~ D.s. stipitatum,
				PER	26	Gymnodinium spp. ~ P. spp.,
				DIA	11	Cyclotella spp,
				sum	85	Navicula sp.
68	YK6	721	203	CHR	73	Ochromonas spp., D. divergens,
				CRY	19	Ch. parva, D.s.,
				DIA	4	Katablepharis ovalis,
				sum	96	R.l.m. nannoplanktica

74	YK6	157	69	CRY	47	R.l.m.,Ochromonas spp.,
				CHR	38	D. divergens, R.l., Ch. parva,
				DIA	13	Stephanodiscus spp.
				sum	98	

Appendix 7. Incubator primary production data. Units of light are microEinsteins.$m^{-2}.s^{-1}$ and units for production are mg $C.m^{-3}.h^{-1}$. The two production replicates are listed one above the other. The column labeled "C.V." contains the mean coefficient of variation for all replicates - it is a crude measure of the variability of the data. "Loc" refers to the station location, see Appendix 1 for the key to these abbreviations.

Sta	Loc	Light	Prod	Light	Prod	Light	Prod	Light	Prod	Light	Prod	C.V.
1	YK1			13.0	0.14	39.2	0.67	126.7	2.49	366.7	4.05	10.95
					0.14		0.78		3.05		3.13	
2	YK3			13.0	0.10	39.2	0.52	126.7	1.66	366.7	2.46	6.18
					0.09		0.53		2.02		2.62	
3	YK5			13.0	0.12	39.2	0.54	126.7	1.95	366.7	3.39	18.87
					0.08		0.43		2.59		3.93	
4	ALX	3.6	-0.01	12.5	0.02	38.3	0.09	126.7	0.61	373.3	0.51	29.44
			0.02		0.01		0.13		0.33		0.79	
5	CHI	3.6	-0.01	12.5	0.04	38.3	0.10	126.7	0.44	373.3	0.91	38.04
			0.03		0.17		0.08		0.64		1.18	
6	DRY	3.6	0.01	12.5	0.27	38.3	0.05	126.7	0.33	373.3	0.46	42.25
			-0.04		0.02		0.04		0.33		0.36	
7	BAP	3.6	0.02	12.5	0.00	38.3	0.12	126.7	0.69	373.3	0.76	20.38
			-0.01		0.00		0.09		0.46		0.64	
8	PRO	3.6	0.02	12.5	0.03	38.3	0.38	126.7	1.25	373.3	1.59	23.50
			0.01		0.02		0.30		1.33		2.11	
9	W2			9.6	0.02	33.1	0.60	108.3	2.28	361.7	4.94	23.13
					0.01		0.64		2.51		3.89	
10	W1W			9.6	0.14	33.1	0.74	108.3	2.29	361.7	3.35	15.02
					0.13		0.57		1.78		2.58	
11	W1E			9.6	0.19	33.1	0.84	108.3	2.48	361.7	5.45	15.71
					0.09		0.85		2.80		4.98	
12	W3			9.6	-0.12	33.1	0.27	108.3	1.40	361.7	2.84	6.52
					-0.08		0.25		1.72		2.91	
13	W5			9.6	0.09	33.1	0.33	108.3	1.79	361.7	3.08	12.20
					0.06		0.42		1.84		3.17	
14	W4			9.6	0.01	33.1	0.19	108.3	0.83	361.7	1.29	22.72
					0.03		0.22		0.75		1.44	
15	YK6			10.4	0.01	35.3	0.36	118.1	2.11	352.2	3.74	8.54
					0.01		0.33		2.06		4.00	
16	YK5			10.4	-0.02	35.3	0.32	118.1	2.22	352.2	3.96	3.23
					-0.02		0.34		2.25		4.23	
17	YK3			10.4	0.05	35.3	0.63	118.1	3.14	352.2	7.82	9.30
					0.06		0.59		2.73		8.08	
18	YK2			10.4	-0.00	35.3	0.42	118.1	2.87	352.2	5.66	1.93
					-0.01		0.43		2.83		5.85	
19	YK1			10.4	0.02	35.3	0.29	118.1	2.22	352.2	4.73	4.67
					0.02		0.29		2.09		5.37	
20	HCW			10.2	-0.03	35.0	0.23	115.0	0.56	343.9	0.93	16.58
					0.09		0.29		0.62		1.36	
21	HCE			10.2	0.02	35.0	0.23	115.0	0.76	343.9	1.07	14.03
					-0.01		0.14		0.86		1.05	
22	CBW			10.2	-0.01	35.0	0.16	115.0	0.46	343.9	0.56	10.37
					0.07		0.18		0.47		0.77	

23	CBE	10.2	0.03	35.0	0.17	115.0	0.76	343.9	1.01	4.93
			-0.01		0.15		0.75		0.93	
24	MCL	10.2	0.02	35.0	0.15	115.0	0.42	343.9	0.49	7.62
			0.03		0.15		0.32		0.47	
25	GOR	10.2	0.01	35.0	0.16	115.0	0.61	343.9	0.81	9.64
			0.01		0.13		0.59		0.80	
26	YK6	8.8	0.08	32.1	NA	117.5	2.11	338.3	4.63	3.46
			0.08		0.54		2.05		4.21	
27	YK5	8.8	0.01	32.1	NA	117.5	2.80	338.3	4.71	47.63
			0.07		0.53		2.10		5.20	
28	YK4	8.8	0.06	32.1	0.41	117.5	2.30	338.3	4.83	5.87
			0.07		0.39		2.01		4.86	
29	YK3	8.8	0.02	32.1	0.36	117.5	2.33	338.3	4.50	3.97
			-0.05		0.32		2.33		4.70	
30	YK2	8.8	0.07	32.1	0.60	117.5	2.71	338.3	NA	3.42
			0.07		0.60		3.04		5.96	
31	YK1	8.8	0.05	32.1	0.52	117.5	2.30	338.3	NA	17.70
			0.08		0.38		2.18		4.49	

n.b.: stations 32-44 were processed in plastic scintillation vials

32	PRO	10.7	-0.26	36.1	-0.30	118.3	0.34	345.8	1.16	7.87
			-0.23		-0.51		0.33		1.41	
33	BAP	10.7	-0.41	36.1	-1.03	118.3	-0.34	345.8	-0.15	
			-0.34		-0.96		-0.67		0.10	
34	DRY	10.7	0.23	36.1	-0.53	118.3	-0.35	345.8	0.38	35.07
			-0.08		-0.88		0.05		0.23	
35	CHI	10.7	-0.87	36.1	-0.81	118.3	-0.69	345.8	0.42	1.63
			-0.46		-0.96		-0.49		0.41	
36	ALX	10.7	0.09	36.1	-0.16	118.3	0.34	345.8	1.31	38.92
			0.05		-0.33		0.90		1.13	
37	MAD	10.7	0.34	36.1	1.30	118.3	5.84	345.8	10.32	10.30
			0.49		1.09		5.60		10.23	
38	YK4	11.7	-0.14	37.3	0.12	117.1	1.16	334.2	2.26	17.10
			-0.07		-0.03		1.18		3.63	
39	YK6	9.4	-0.59	32.9	-0.56	113.3	-0.61	355.0	1.36	46.35
			-0.95		-1.38		-0.66		0.69	
40	YK5	9.4	-0.54	32.9	-1.07	113.3	-0.98	355.0	-0.34	
			-0.80		-1.00		-0.93		-0.09	
41	YK4	9.4	-0.71	32.9	-0.65	113.3	0.12	355.0	2.56	16.91
			-0.72		-1.05		0.15		3.26	
42	YK3	9.4	-0.39	32.9	-1.25	113.3	-0.46	355.0	1.66	5.34
			-0.70		-1.37		-0.61		1.54	
43	YK2	9.4	-0.20	32.9	-0.51	113.3	0.35	355.0	2.12	108.87
			0.03		0.37		2.69		NA	
44	YK1	9.4	-0.41	32.9	-0.71	113.3	0.12	355.0	2.15	5.54
			-0.46		-0.77		-0.08		2.33	
45	YK6	9.4	0.01	32.4	0.27	110.4	1.45	347.9	4.02	19.13
			0.01		0.31		1.40		4.11	
46	YK5	9.4	0.00	32.4	0.23	110.4	1.38	347.9	4.33	20.88
			0.01		0.26		1.45		4.21	
47	YK4	9.4	0.02	32.4	0.20	110.4	1.26	347.9	3.39	8.53
			0.01		0.21		1.23		2.98	

48	YK3			9.4	0.01	32.4	0.26	110.4	1.50	347.9	3.10	2.66
					0.01		0.25		1.54		3.38	
49	YK2			9.4	0.01	32.4	0.18	110.4	1.22	347.9	3.18	5.00
					0.02		0.18		1.21		3.11	
50	YK1			9.4	-0.00	32.4	0.29	110.4	2.22	347.9	5.53	8.24
					0.01		0.26		1.96		4.95	
51	YK6			10.3	0.09	31.8	0.52	108.3	1.98	323.3	3.01	14.41
					0.06		0.52		1.59		3.38	
52	YK5			10.3	0.06	31.8	0.57	108.3	2.24	323.3	3.74	25.32
					0.01		0.51		2.30		3.70	
53	YK4			10.3	0.07	31.8	0.54	108.3	1.91	323.3	3.26	8.59
					0.08		0.48		1.96		4.29	
54	YK3			10.3	0.05	31.8	0.49	108.3	2.26	323.3	5.14	8.58
					-0.01		0.40		2.47		5.58	
55	YK2			10.3	0.09	31.8	0.69	108.3	3.16	323.3	6.14	8.90
					0.08		0.66		2.64		5.14	
56	PRO			10.3	0.05	33.3	0.40	111.3	1.53	327.9	3.30	8.64
					0.05		0.35		1.53		4.03	
57	BAP			10.3	0.04	33.3	0.29	111.3	1.39	327.9	2.74	5.53
					0.04		0.27		1.32		2.86	
58	DRY			10.3	0.01	33.3	0.22	111.3	1.01	327.9	2.14	9.30
					0.02		0.22		1.08		2.28	
59	CHI			10.3	0.00	33.3	0.21	111.3	1.12	327.9	2.42	37.64
					0.02		0.19		1.03		4.49	
60	ALX			10.3	0.03	33.3	0.27	111.3	1.17	327.9	2.67	11.68
					0.02		0.26		1.24		2.42	
61	MAD			10.3	0.11	33.3	1.41	111.3	7.02	327.9	14.50	2.33
					-0.00		1.38		7.37		14.00	
62	HCW			11.0	0.06	35.8	0.73	119.6	2.74	345.0	5.10	17.81
					0.02		0.65		2.70		4.93	
63	HCE			11.0	0.07	35.8	0.63	119.6	2.26	345.0	3.64	10.35
					0.09		0.52		2.13		3.90	
64	CBW			11.0	0.01	35.8	0.42	119.6	1.82	345.0	3.66	10.24
					0.01		0.41		NA		3.20	
65	CBE			11.0	0.01	35.8	0.39	119.6	1.54	345.0	2.71	9.22
					-0.01		0.27		1.49		2.68	
66	MCL			11.0	0.01	35.8	0.14	119.6	0.70	345.0	1.27	4.38
					-0.01		0.14		NA		1.42	
67	GOR			11.0	0.03	35.8	0.15	119.6	0.65	345.0	0.89	7.58
					0.02		0.16		0.64		0.99	
68	YK6			10.8	0.03	36.3	0.39	115.4	1.72	319.6	4.78	13.90
					0.04		0.56		1.63		3.85	
69	YK5			10.8	0.03	36.3	0.31	115.4	1.57	319.6	3.47	0.53
					0.03		0.31		1.58		3.50	
70	YK4			10.8	0.02	36.3	0.34	115.4	1.63	319.6	4.54	10.50
					0.03		0.36		1.75		4.03	
71	YK3			10.8	0.02	36.3	0.33	115.4	2.01	319.6	5.84	16.56
					0.01		0.35		1.87		5.61	
72	YK2			10.8	0.03	36.3	0.38	115.4	2.03	319.6	5.79	10.69
					0.02		0.41		2.27		4.99	
73	YK1			10.8	0.02	36.3	0.22	115.4	1.66	319.6	3.83	7.99
					0.02		0.21		1.34		3.62	
74	YK6	10.1	0.31	27.3	0.23	57.5	0.80	125.6	2.00	289.2	3.36	34.09
			0.06		0.56		0.74		1.80		3.26	

75	YK5	10.1	0.11	27.3	0.57	57.5	1.49	125.6	5.36	289.2	4.80	11.67
			NA		0.57		1.62		3.57		NA	
76	YK4	10.3	0.06	27.8	NA	58.9	1.04	126.4	2.57	288.9	4.62	5.15
			0.06		0.38		0.88		2.47		4.87	
77	YK3	10.3	0.07	27.8	NA	58.9	1.24	126.4	3.51	288.9	5.87	6.02
			0.06		0.42		1.29		3.16		5.19	
78	YK2	10.3	0.07	27.8	0.41	58.9	1.29	126.4	3.03	288.9	5.25	6.67
			0.07		0.49		1.22		3.05		6.37	
79	YK1	10.3	0.05	27.8	0.42	58.9	1.31	126.4	3.32	288.9	5.52	18.77
			0.02		0.50		1.97		3.43		5.80	

Appendix 8. Primary production parameters, integral daily primary production, total phytoplankton biomass, and chlorophyll concentration data. The units of alpha are mg $C.mg^{-1}$ $chl.Einstein^{-1}.m^2$. The units of Pm are mg $C.mg^{-1}$ $chl.h^{-1}$. The units of daily production are mg $C.m^{-2}.d^{-1}$. The units of phytoplankton biomass and chlorophyll are $mg.m^{-3}$. "Loc" refers to the station location, see Appendix 1 for the key to these abbreviations.

Sta	Loc	alpha	PBm	Daily Prodn	Phyto Bioms	Chlorophyll Std.	Chlorophyll Spect	Chlorophyll HPLC
1	YK1	1.33	0.63	110		5.7	5.5	4.8
2	YK3	0.88	0.43	138		5.9	4.9	3.1
3	YK5	1.15	0.70	216		5.2	3.9	2.8
4	ALX	1.07	0.54	71		1.2	0.9	0.7
5	CHI	2.09	0.95	108		1.1	0.9	0.8
6	DRY	4.28	0.51	86		0.8	0.7	0.5
7	BAP	1.46	0.70	73		1.0	0.9	0.6
8	PRO	1.69	0.42	237		4.4	4.0	3.0
9	W2	2.17	1.30	300	411	3.4	3.1	2.1
10	W1W	3.20	1.29	230	394	2.3	2.4	1.0
11	W1E	4.34	2.27	295	288	2.3	2.4	0.8
12	W3	1.99	1.03	52	214	2.8	2.5	2.5
13	W5	2.12	1.12	136	893	2.8	2.6	1.7
14	W4	0.95	0.51	101	336	2.7	2.4	1.9
15	YK6	1.13	0.79	221		4.9	4.5	4.3
16	YK5	1.36	0.93	217		4.4	4.0	2.8
17	YK3	1.72	1.50	387		5.3	5.1	5.0
18	YK2	1.60	1.17	304		4.9	4.5	5.1
19	YK1	1.58	1.15	159		4.4	4.1	4.2
20	HCW	1.95	0.88	79	105	1.3	1.2	0.7
21	HCE	1.12	0.50	125	325	2.1	1.6	1.4
22	CBW	1.49	0.55	86	162	1.2	0.9	0.7
23	CBE	1.21	0.54	150	266	1.8	1.4	1.1
24	MCL	1.14	0.40	135	164	1.2	0.8	0.6
25	GOR	1.57	0.73	191		1.1	0.8	0.5
26	YK6	1.64	1.13	265	838	3.9	3.8	2.5
27	YK5	1.65	1.13	295		4.4	4.2	2.9
28	YK4	1.81	1.38	293		3.5	3.3	2.3
29	YK3	2.28	1.35	322		3.4	3.2	2.2
30	YK2	2.16	1.53	385		3.9	3.9	2.4
31	YK1	2.10	1.45	144		3.1	2.9	1.9
32	PRO	NA	NA	NA		2.0	1.8	1.7
33	BAP	NA	NA	NA		1.3	1.1	1.1
34	DRY	NA	NA	NA		1.2	0.9	1.0
35	CHI	NA	NA	NA		1.4	1.1	1.2
36	ALX	NA	NA	NA		1.2	1.0	0.9
37	MAD	NA	NA	NA		7.6	6.9	7.1
38	YK4	NA	NA	NA		2.9	2.6	2.1
39	YK6	NA	NA	NA	549	2.8	2.4	1.7
40	YK5	NA	NA	NA		1.9	1.6	0.9
41	YK4	NA	NA	NA		2.2	2.1	1.1
42	YK3	NA	NA	NA		2.6	2.3	1.1
43	YK2	NA	NA	NA		2.1	1.9	1.3

44	YK1	NA	NA	NA		2.0	1.8	1.1
45	YK6	1.83	1.56	163	571	2.6	2.2	1.5
46	YK5	1.99	1.78	208		2.4	2.0	1.3
47	YK4	1.61	1.33	147		2.4	2.1	1.5
48	YK3	1.76	1.16	164		2.8	2.6	1.7
49	YK2	1.71	1.43	158		2.2	2.4	1.8
50	YK1	2.78	1.87	157		2.8	2.5	2.0
51	YK6	2.03	1.06	210	409	3.0	2.7	2.0
52	YK5	2.17	1.16	219		3.2	2.8	2.3
53	YK4	2.74	1.57	214		2.4	2.2	1.4
54	YK3	2.29	1.58	273		3.4	3.1	2.4
55	YK2	2.41	1.45	341		3.9	3.6	3.1
56	PRO	2.80	1.83	198		2.0	1.7	1.2
57	BAP	2.76	1.75	238		1.6	1.3	1.2
58	DRY	2.35	1.58	211		1.4	1.2	0.9
59	CHI	2.49	2.16	213		1.6	1.4	0.9
60	ALX	2.15	1.41	222		1.8	1.5	1.2
61	MAD	2.73	1.83	508		7.8	6.9	6.4
62	HCW	2.75	1.79	270		2.8	2.4	1.4
63	HCE	2.33	1.35	280	658	2.8	2.3	1.5
64	CBW	1.55	1.07	231	414	3.2	2.7	2.0
65	CBE	1.51	1.00	201	741	2.7	2.3	1.1
66	MCL	1.76	1.22	178	105	1.1	0.8	0.4
67	GOR	1.85	0.94	140		1.0	0.8	0.6
68	YK6	2.51	1.80	214	721	2.4	1.9	1.5
69	YK5	2.24	1.58	176		2.2	1.9	1.3
70	YK4	2.42	1.79	208		2.4	2.0	1.8
71	YK3	2.16	1.91	257		3.0	2.6	2.1
72	YK2	2.90	2.16	266		2.5	2.2	1.8
73	YK1	2.09	1.55	101		2.4	2.1	1.6
74	YK6	4.08	1.95	188	157	1.7	1.4	1.1
75	YK5	4.37	1.85	315		2.6	2.3	1.9
76	YK4	3.28	2.16	193		2.2	2.0	1.5
77	YK3	3.25	2.05	264		2.7	2.4	2.0
78	YK2	3.28	2.15	249		2.7	2.3	2.2
79	YK1	2.80	1.72	153		3.3	2.9	2.5